SCIENCE IN THE MODERN

FIRE AND HEAT

by

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With Diagrams
and Photographs

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CHAPTER I

MAN'S MASTERY OF FIRE

MAN is the greatest of the animals. He can speak, think, and reason. He cultivates the land and grows much of his food. He has learned to live by "trading"—by selling things of which he has too much and buying other things which he needs. He is the only creature who makes and uses tools. But one of his greatest successes has been the discovery of Fire. He has found out how to make fire, how to control it, and how to use it. Certain other animals can make noises and, perhaps, "talk" to each other in a very simple way; many can think, though not so well as Man; not one, however, has tried to make or use a fire. Most animals, in fact, are afraid of fire. Man's discovery of fire has enabled him to do many things which other animals cannot do, indeed Man's mastery of the world is largely due to his mastery of fire.

We do not know how the first fire was made. Early fires on the earth were certainly caused by Nature, not by Man. Some were caused by lightning in a storm; others, perhaps, by the hot material which came out of a volcano. Quite possibly, at times, the heat of the sun set light to some dry grass or leaves. At first Man, like other animals, was probably afraid of fire. He saw that fire could destroy a forest; he knew that fire could hurt his body. So great was the power of fire that he feared it and worshipped it. Gradually, however, with his better powers of thinking, he overcame his fear. Probably he overcame most of his fear when he discovered how to make fire for himself, but, undoubtedly, he learned some of the uses of fire before he could make one where and when he wished. Throughout the ages he has learned more about fire, how to control it, and how to use it in many ways. Now fire is no longer a master or a god ; it is a servant.

(*By courtesy of Bowater's Newfoundland Pulp and Paper Mills Ltd.*)

Fire out of control—a great forest fire.

We can only guess how Man first learned that a fire was useful and what uses he made of it. By taking a burning stick from some fire which had been started naturally, he could make a fire at his own "home." He could keep the fire burning by adding more dry grass, leaves, and wood. The fire served the chief purpose of frightening animals away. At some time he learned the advantages of cooking parts of his food. He discovered, by some accident, that flesh roasted in front of a fire tasted better. Then he found that roasted flesh would keep longer, without going bad, than uncooked flesh. Later he made simple ovens. Perhaps he dug a hole in the ground, filled it with dry wood, and covered the wood with stones. He set light to the wood and, when the stones had become hot, buried the food in them. It must have been much later that Man learned to cook food by heating it with boiling water or with steam. He could not use such methods until he had learned how to make pots for holding water.

Again, at some early date, Man found how fire could be used to make certain metals from the rocks. Perhaps he rested his cooking pot on stones in the fire, and once he happened to use some pieces of copper ore. After the fire had died down he found some little pieces of shiny, brown metal among the ashes. He had heated a mixture of copper ore and charcoal (from the half-burned wood in the fire); this is a common way of getting certain metals from their ores (p. 117). After this discovery, of course, he purposely made the metal by heating the ore in his fire. Some time later, he found out how to make the metal which we now call bronze. This is a mixture of copper and tin. In some parts of the world (for example, in south-west England) copper ore and tin ore are found in the ground together. Perhaps by accident at first, he put both kinds of ore in his fire.
Bronze, he discovered, was a very useful metal. It was hard and tough, but he could shape it by "hammering" (probably with heavy stones). He could make a tool with a sharp edge for cutting. It is not so easy to get iron from its ore and this metal was probably not discovered until very much later.

Man, we have said, may have known some of the uses of fire long before he knew how to start a fire himself. He could only start his fire from a natural fire, and he had to be careful not to let it go out. If it did go out, he would have to find another tribe which had a fire and take a burning stick from them—or wait until another fire started naturally! An early way of starting a fire was by friction (p. 21). When two rough surfaces are rubbed together they become hot. With skill, and much hard work, the heat can be made to start a fire. This idea was used in many ways. One way was to slide a wooden stick (shaped something like a chisel) quickly backwards and forwards in a groove in another piece of wood. Very small bits of wood were rubbed off in the groove and the heat produced by the rubbing set them alight. Another way was to hold a hard, dry, pointed stick in a hole in a piece of soft, dry wood, and turn the stick quickly between the hands (Fig. 1). These ways, of course, were very slow. A man might think that he had spent several hours very usefully if, in the end, he had started a fire.

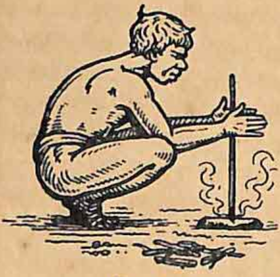

Fig. 1.

It is possible that early Man also discovered how to start a fire by striking two stones together and so making sparks. He would strike the stones over some material which burned easily, such as dry grass, and hope that the sparks would set it alight. He found, no doubt, that a current of air, made with the hands or by blowing, would make a spark glow more brightly and, perhaps, cause the grass to burst into flame. One kind of stone was particularly suitable for this purpose. We now call this kind of stone "pyrites," a name which means "the stone which makes fire." We use a similar idea in the modern petrol lighter (p. 27).

To-day we can make a fire so easily that we forget how fortunate we are. We can buy a box of matches very cheaply. A man who wants to light a cigarette often asks a friend "for a light." How different that is from rubbing two sticks together for several hours in the hope of starting a tiny fire! We also know other ways of making heat. We know, for example, how to make it by electricity.

We do not often realise how much we owe to fire. Think of the various things in your home. There is scarcely one which could have been made without fire. For all of them heat was used, in some way, either to make the material, or to shape it, or to fasten the different parts together. Without fire we could not make good bricks; we could only make very poor ones by drying clay in the sun. We should have very few metals. Only a few metals are found "free," that is, not joined to other substances in the rocks, and this supply would not be enough for Man's needs. Other metals could not be made because heat is needed to get them from their ores. Iron, the metal which we use so widely, would be almost unknown, and, even if we had it, we could not shape it. Without fire we should have no glass, no earthenware, no cement. We could not cook our food. We should have to pull our carts ourselves, or use animals, for we should have no steam-engines or motor cars.

Although Man is now the master, and fire his servant, there are times when the master fails to control the servant. We have all heard of the great forest fires in North America, the bush fires in Australia, and the fires which sometimes burn for weeks in an oilfield. The only difference between a fire in an iron-making furnace and one which destroys a forest or a house, is that the first is controlled and the second is not controlled. Man has much to learn of the ways of stopping fires from starting in unwanted places and of putting out such fires if they begin. Methods of fire-fighting are always being improved. We are learning how to make and use materials which cannot burn. Asbestos is such a material.

(*Fox Photos Ltd.*)

Fire-fighting—a man in an asbestos suit among the flames of a burning aeroplane.

In this book we shall try to learn something of the nature of fire—what it is and how it burns. We shall read about other ways of making heat. We shall then study some of the things which heat can do. And we shall read about some of the uses which Man makes of heat, particularly of the heat produced by Fire.

CHAPTER II

THE NATURE OF BURNING

WHAT is fire? This seems a simple question to answer. We all know that if we set light to a piece of paper (or wood, or coal) it burns brightly and becomes hot. Flames and smoke are made and ashes are left behind when the burning has stopped. But what exactly happens when a thing burns? Why must we set light to it first? What is a flame? What is smoke? What are the ashes? These are the kinds of questions we shall try to answer.

Although Man learned how to make fire thousands of years ago, it was not until the end of the eighteenth century (that is, less than 200 years ago) that the process of burning was understood. The explanation of what happens when something burns was really the beginning of modern chemistry.

If a thing is to burn it must have air. If we light a fire in a bucket it soon goes out because it cannot get enough air. But if we make some holes near the bottom of the bucket, so that air can get in, the fire burns well. When we light a fire we lay the sticks loosely, leaving plenty of spaces for the air to get in. A man draws air through a cigarette when he smokes it; the air helps the tobacco to burn. If we stand on a lighted match it goes out; we stop the air from reaching it. We therefore ask "What part does the air play in burning?" In science we try to find the answers to our questions by doing experiments. Here is an experiment which you can try yourself.

You need a short candle, a dish, and a large jam jar. Melt the lower end of the candle and stick it in the middle of the dish. Nearly fill the dish with water. Light the candle and stand the jar upside down over it (Fig. 2). Watch the level of the water in the jar. Where is the level when the jar is first put in place? What happens to the candle after a short time? Where is the level of the water then? Now lift the jar and dish together and, holding them firmly, turn them right over so that the dish rests over the top of the jar. (In doing this you will spill the water in the dish.) Take a lighted match (or a piece of burning paper) and, quickly lifting the dish, put it inside the jar. Does it keep alight?

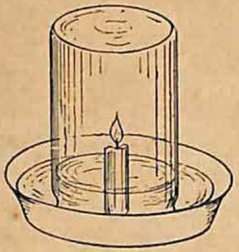

FIG. 2.

While the candle is burning, the level of the water in the jar rises. Some of the air *is used up* during the burning. The water comes in to take the place of the air which is used up. After a short time the candle goes out although there still seems to be some "air" in the jar. When we test this "air" we find that things cannot burn in it. It seems that the air consists of two parts; one part which allows things to burn and which is used up during burning, and one part which is useless for burning. Scientists have proved that air is a mixture of gases. The gas in which things can burn is called oxygen. It forms one-fifth of the air. The rest of the air (four-fifths) consists chiefly of a gas called nitrogen.

Ordinary burning cannot take place without oxygen. If a burning thing has plenty of air round it, it gets all the oxygen it needs; if air cannot reach it, there is not enough oxygen, and the burning stops. Scientists have been able to make pure oxygen. As you would guess, things burn very well in pure oxygen. A piece of wood which is only glowing red immediately breaks into flame when put in a jar of oxygen. If red-hot iron wire is put in a jar of oxygen it burns brightly.

We have seen, not only that oxygen is necessary for burning, but also that it is used up during burning. What happens to it ? In 1777 a French scientist called Lavoisier tried some very important experiments. In his first experiment he heated some tin (the metal) in a closed container. The tin did not burn with a flame, but it slowly turned into a kind of grey ash. We might say that there was very slow burning but not a fire. When he opened the container some air rushed in. The tin had used up the oxygen in the air during its very slow burning and, when the container was opened, air rushed in to take its place. He found, by very careful measurements, that the ash weighed more than the tin with which he had started and that the gain in weight was exactly equal to the

(Picture Post Library)

Antoine Lavoisier (1743–1794) performing his famous experiment on the composition of the air.

weight of oxygen which had been used up. It seemed, then, that during the burning the tin *joined* with oxygen and made a new substance (the ash).

In his second experiment Lavoisier heated some mercury (or " quicksilver ") in a container for several days. The mercury gradually changed into a red powder. This was *very* slow burning. Again, some of the air was used up. The mercury joined with the oxygen to make the red powder. Then he took some of the powder and heated it very strongly. A gas was set free and mercury was left behind. Things burned very well in this gas ; it was oxygen. He was therefore able to *prove* that the red powder contained oxygen. It was quite clear that the mercury had joined with oxygen of the air during its very slow burning.

Tin, mercury, and oxygen are *elements*. We cannot, by any means, break them up into simpler substances. When two (or more) elements join together they make a *compound*. The red powder formed when mercury joins with oxygen is a compound. Notice that a compound is quite different from the elements from which it is made. Mercury is a silver-like liquid, oxygen is an invisible gas, but the compound made from them is a red powder. A compound formed by the joining of an element with oxygen is called an oxide. The red powder is mercury oxide ; the grey ash in Lavoisier's first experiment was tin oxide. Usually we cannot decompose (break up into simpler parts) an oxide by heating ; mercury oxide is an exception.

Tin and mercury " burn " very slowly and do not make a flame. Now let us think about some materials which burn more easily. Let us start with a piece of coal. Coal consists chiefly of an element called carbon. When a piece of coal burns, the carbon joins with oxygen in the air. The oxide which is made is called carbon dioxide.

As carbon dioxide is a gas, it escapes while the coal is burning and we do not notice it. Paper, wood, rag, oil, and many other materials which burn well, are compounds (or mixtures of various compounds). These compounds consist of carbon, hydrogen,[1] and, often, oxygen. When such materials burn, both the carbon and the hydrogen join with oxygen in the air to form oxides. The carbon, we know, makes carbon dioxide. Hydrogen oxide is well known to you although you may not know it by that name. Hold a piece of cold glass, or a plate, above a candle flame. A black patch is formed on the glass (which we shall explain later) but, if you look carefully, you will also see a faint mist. The mist consists of very small drops of water. Yes, hydrogen oxide is water. We do not usually see the water which comes from the burning material because it is in the form of a vapour. Like the carbon dioxide, it escapes unnoticed.

We often think that we destroy a thing when we burn it. It is true that the piece of paper (rag, etc.) is no longer paper. But we have not destroyed the elements of which the paper is made; new compounds have been made. When we burn a candle, some of the wax is used up, but in its place we make carbon dioxide and water. Further, these substances weigh more than the actual wax, for the carbon and hydrogen have joined with some oxygen.

We learn, then, that burning is a process in which elements join with oxygen. We call the process oxidation. The oxidation may be slow, as in the " burning " of foods inside the body (p. 66) and in the burning of mercury. It may take place quickly, and give out much heat, as in the burning of wood and paper. Quick, hot burning makes a fire. This is the subject of our next chapter.

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[1] Hydrogen itself is a gas; it is the lightest element known.

CHAPTER III

FIRE, SMOKE, AND FLAME

WE have learned that when things burn, the elements of which they are made join with oxygen in the air and make new substances called oxides. When tin burns it makes tin oxide; when carbon burns it makes carbon dioxide. Although we often make a fire with carbon (e.g. with coal) we would not think of trying to make a fire with tin. What is the difference between the burning of carbon and of tin?

Most elements can join with oxygen and make oxides but, at ordinary temperatures, such as the temperature of the air, the process is usually very slow. We can make the process quicker by heating. If we heat a piece of tin (as in Lavoisier's experiment) it forms the oxide fairly quickly; if we put a piece of coal on a hot fire it catches alight and burns well. In both cases the substances must be kept hot. Now we come to the important difference between the burning of the tin and the carbon. The tin does not keep itself hot; we must supply heat to it, all the time, from outside (e.g. from a fire). But once carbon has been made hot enough to begin to burn, it keeps itself hot, and so goes on burning. Heat is made during the process of burning and this heat enables the burning to continue.

Let us think, then, what happens when we set light to a candle. The candle wax consists of compounds of carbon and hydrogen. When we hold a lighted match near the candle, the heat of the match melts a little of the wax in the "wick," turns it into vapour, and makes the vapour begin to burn. The burning vapour is the flame. Then the heat of the flame melts more wax, turns it to vapour, and makes it burn. So, as you can see, the *candle goes on burning* once it has been lit. In a similar way a piece of paper, or wood, or coal, goes on burning after it has been lit.

A material which easily catches alight and then goes on burning is said to be "inflammable." Paraffin (kerosene) is very inflammable. It very easily catches alight and burns. Paper is inflammable, but not so inflammable as paraffin. We say that iron is non-inflammable. It does not burn (in air) unless it is made very hot and it does not then keep itself alight. We notice that before a material can catch alight, that is, burn well enough to keep itself burning, it must be heated above a certain temperature. Paper catches alight easily. The heat from a match is enough to make it begin burning. A piece of coal needs to be made hotter before it begins to burn. Have you noticed that when you light a fire you start with materials which are very inflammable and gradually set light to materials which are less inflammable? Thus you first set light to some paper, then the paper sets light to some sticks, and then, perhaps, the sticks set light to the coal. Each material has to be made hot enough for it to begin to burn.

When we think of a fire we usually think of heat, smoke, and flame. Ash is often left behind when the fire has gone out. Let us examine each of these in detail. The heat is produced by the actual process of burning. It is made when the elements in the burning material join with oxygen. The ash usually consists of any non-inflammable parts of the material or of any parts of the material which did not get enough oxygen and failed to burn.[1]

What is a flame? A flame consists of burning vapours and tiny bits of very hot solids. We can learn a lot by studying a candle flame. The candle flame has a pointed shape. This is because the hot vapours, and the hot air round them, rise (p. 94). You can see four different parts in the flame (Fig. 3 a). Right at the bottom, below the wick, the flame is bright blue. Above the wick there is a dark part and above and around this there is the big yellow part. If you look carefully you will see a faint layer, almost invisible, all round the outside of the flame.

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[1] An ash may contain a solid oxide (as in Lavoisier's experiment) but the oxides of inflammable materials are usually gases.

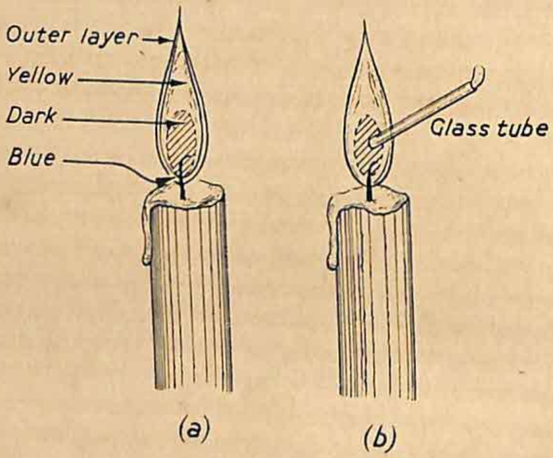

FIG. 3.

We know that air is necessary for burning. Air can only properly reach the outside of the flame; it cannot reach the middle of the flame. It reaches the bottom of the flame—this is where the vapours burn with a blue colour—and the sides of the flame. The faint layer on the outside consists of vapours which are burning properly. It is the hottest part of the flame. In the middle, yellow part of the flame the vapours are not burning properly because they cannot get enough air. Lower a white plate (or a sheet of stiff paper) into the flame for a few seconds. Look at the black mark made on it. It consists of carbon—just like the soot in a chimney. In this middle part of the flame some of the carbon from the compounds in the wax remains unburnt. Many very small particles of carbon only glow in the burning vapour instead of burning right away. It is these glowing particles which send out light and make the flame yellow. When the flame is cooled by the plate these particles do not glow but settle, as black soot, on the plate.

Just above the wick the vapours have not become hot enough to burn. The dark part of the flame consists of these cooler, unburnt vapours. If you can get a short piece of glass tubing you can try an interesting experiment. Hold the tubing with one end in the dark part of the flame (Fig. 3 b). Hold a lighted match at the other end of the tube. A small bluish flame is formed there. Some of the unburnt vapour from the candle flame goes along the tube and burns at the other end.

Smoke consists chiefly of little particles of carbon which escape unburnt from the flame. They are carried upwards by the current of hot air which rises from the flame. Yellow flames, which contain particles of unburnt carbon, are usually smoky.

Many flames which you ordinarily see are similar to a candle flame. Look at the flame of burning paper, the flames on burning coal, and flame in an oil lamp. The flames are yellow and smoky. We understand that these flames are not the hottest kinds of flames because they contain unburnt carbon. All the smoke which escapes from the fire, and all the soot which collects in a chimney, is wasted material. If this carbon had burned more heat would have been made.

We can make a hotter flame if we supply air to the middle of the flame. Then all the carbon will burn. Such a flame will give less light (it may be faint blue instead of yellow) and be less smoky. It is important to notice that a flame which is not giving much light often means that the burning is more complete and that the flame is giving more heat.

(*By courtesy of the British Oxygen Co. Ltd.*)
Mending a plough-share with the help of an oxy-acetylene blow-pipe.

A scientist often uses a "Bunsen burner" for heating things in his experiments. Fig. 4a is a drawing of a Bunsen burner. The flame is produced by burning coal-gas.[1]

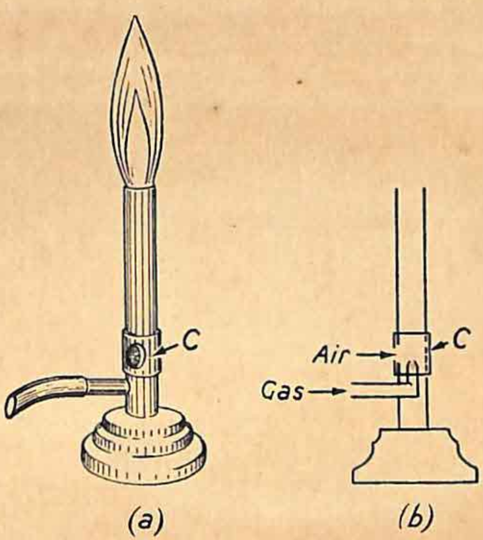

FIG. 4.

Near the bottom of the burner there is a hole which can be opened and closed by means of movable collar C. Fig. 4b shows the inside of the burner. Notice that the end of the pipe by which the gas enters is level with the hole. When the hole is closed, the gas rises to the top of the burner and burns there with a yellow, smoky flame. The flame is like a big candle flame. When the hole is opened. the rush of gas draws in some air. The mixture of gas and air rises up the burner. The flame has air *inside* it. It is no longer yellow and smoky. In the middle there is a blue part consisting of unburnt gas. The outer part of the flame is pale purple. Here the gas is burning. This part is very hot.

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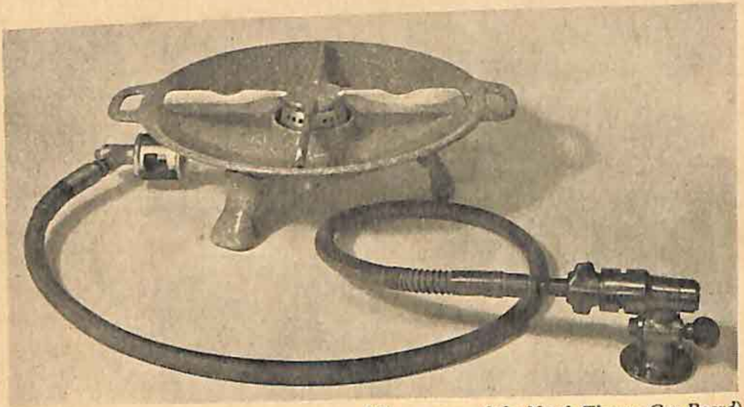
[1] Coal-gas is well known in England, and other countries which have a plentiful supply of coal, but is almost unknown in certain other countries. It is made by heating coal and is sent to houses and factories through pipes in the ground.

In countries where coal-gas is supplied to houses, gas-burners are often used for heating kettles, saucepans, etc.



(By courtesy of the North Thames Gas Board)

A gas burner for boiling pots of water. Notice the hole by which air enters and mixes with the gas.

If you can examine a " gas ring," as used for such purposes, you will find that it is similar to a Bunsen burner. You can see the hole by which the air enters. The mixture of gas and air comes out through a ring of holes so that there is a ring of flames. A gas-oven, as used for baking, is really a box with a row of gas-burners placed on each side at the bottom.

A hotter flame than that of a Bunsen burner is produced by a " blow-pipe." This is a gas-burner made so that a stream of air can be *forced* into the middle of the flame (e.g. from " bellows "). The flame, which is thin and

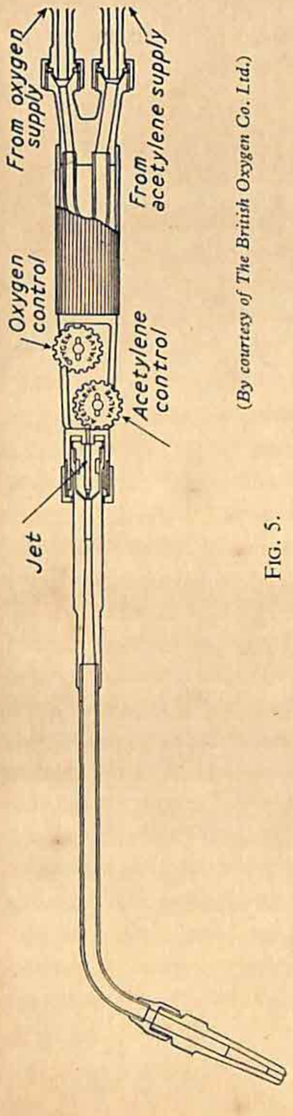


FIG. 5.

(*By courtesy of The British Oxygen Co. Ltd.*)

pointed, is very hot. The hottest of all flames is given by the oxy-acetylene blow-pipe (Fig. 5). Acetylene is a gas made by the action of water on "carbide." In this blow-pipe, oxygen is forced into the middle of the flame. It is used for welding (p. 123) and for "cutting" steel. The steel is first made white-hot at the place where it is to be cut and then the supply of acetylene is cut off. The steel burns away in the stream of oxygen, making a shower of bright sparks. In this way thick plates of steel can be "cut" quite easily.

CHAPTER IV

THE WAYS IN WHICH HEAT IS PRODUCED

THE chief use of a fire, of course, is for producing heat. A fire is used to warm a building, to cook our food, to melt metals, to boil water in a steam-engine, and so on. We cannot have a fire which does not produce heat. We can, however, produce heat without a fire. Our own bodies, for example, produce heat, but there are no fires inside us! The middle of a heap of rotting grass becomes hot, axles on which wheels are turning become hot, the wire in an electric lamp is made hot by the current. We shall see, in this chapter, that there are three chief ways in which heat is produced. Fire is an important example of one of these ways.

If you rub your hand backwards and forwards on a rough surface, such as rough cloth or a piece of sandpaper, it becomes hot. There is "friction" between your hand and the surface. Friction is a force which tries to stop one thing from sliding on another. In order to move your hand you must push, that is, you must supply a force to overcome the friction. There is friction between any two surfaces which slide on each other, for no surface is perfectly smooth. There is friction, for example, between the ground and a sack of potatoes (or other produce) which you may drag along, between the wheels of your bicycle and their axles, between a ship and the water through which it moves. A force must be supplied to overcome the friction; you must pull the sack, press on the bicycle pedals and drive the ship.

The friction " resists " (opposes) the movement ; there is " resistance " to the movement. The force which we supply overcomes the resistance. When we use a force to overcome a resistance and so move something, we say that we do some work. The scientist, you see, uses the word " work " with this special meaning. Whenever we do work in overcoming friction, heat is produced. Hence your hand becomes hot when you rub it on a rough surface, the axles of wheels in machines become hot, and so on. We have read how early Man depended upon heat produced by friction for starting a fire.

We can do work in overcoming other kinds of resistance. We do work when we saw a piece of wood, bore a hole in a metal bar, or compress some air (as in pumping up a bicycle tyre). In all such cases heat is produced. The tools which we use, and the material on which we work, become hot. Have you noticed, for example, that a bicycle pump becomes hot at its end when you use it? You can find many similar examples of producing heat by overcoming a resistance.

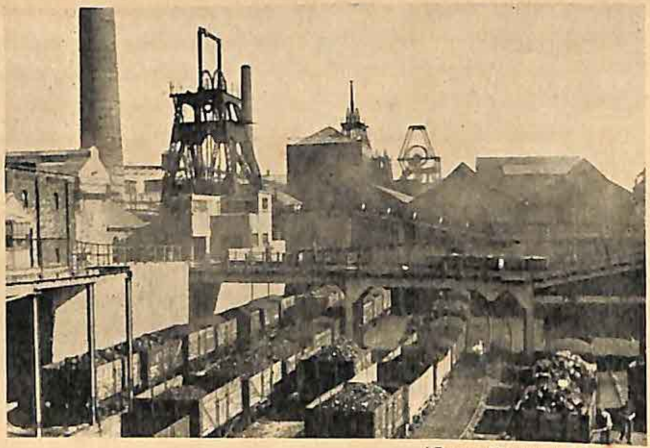
Although friction (and other resistances) are useful at times—we could not walk, for example, without the friction between our feet and the ground—the heat which is produced is not often useful. It is not in a convenient place and usually there is not enough of it. We make use of the heat produced by friction when we strike a match. The oil in a Diesel engine (p. 136) is exploded by the heat of compressed air.

The second way in which heat can be produced is by chemical action. Heat is often set free when two substances act together to form new substances. If, for example, you dissolve a piece of metal in an acid (e.g. zinc in sulphuric acid) the liquid becomes quite hot. During the war " fire bombs " were used to start fires in the enemy's towns. These depended upon the heat produced when the substances in the bombs acted together. By far the most important kind of chemical action in which heat is produced is oxidation, that is, the joining of elements with oxygen. We have already learned that burning is an oxidation process. If the burning is quick, and produces enough heat to keep the action going, we call it a fire.

Wood, coal, oil, and other material which we use for burning, are called " fuels." The burning of fuels is the most important process in the world. We use the process to give us heat, and, by means of the steam-engine, to give us power. Without such fuels Man could not make big supplies of metals and other materials, he would still have to depend upon the power of animals to pull his carts, and factories could only be built in places where water-power (e.g. water-wheels) could be used to drive the machines.

Perhaps wood is the best known fuel. Although we often burn it in our fires at home, it is not an important fuel. It gives less heat than the same weight of coal and, because it takes up more room, cannot be carried about and stored so easily. It is of greater importance in those countries which have poor supplies of coal but plenty of wood in the forests.

There are two very important fuels : coal and oil. Coal is burned in millions of fires, in houses and factories, to produce heat. It is also a most important source of power. Steam-engines (and steam-turbines), heated by burning coal, are used for pulling trains, driving certain kinds of ships, and working machines in factories. In England, and other countries where coal is plentiful, they are also used for driving the great " generators " for producing electricity. Actually it is rather wasteful to burn coal,



(*Crown Copyright Reserved*)

Coal must be carried from the mine to other parts of the country. In this picture the railway trucks are being loaded. Notice the different sizes of coal in the separate trains.

because it does not burn properly. The soot, smoke, and flame show us that the burning is not complete (p. 15). Further, there are other valuable substances in the coal which are lost when it burns. If, instead, the coal is heated in a closed container so that it does not get enough air to burn, certain gases and vapours are driven off and a grey, easily-broken solid is left behind.[1] The mixture of gases, most of which are inflammable, is called coal gas. It is much used as a fuel. (A Bunsen burner uses coal gas.) The grey solid is called coke. It burns very well if it is made hot enough first, and, for some purposes, is a more convenient fuel than coal itself. The vapours form a liquid from which " fertilizers " can be made (substances put on the soil to help crops to grow) and also form tar from which dyes, scents, and certain medicines are made. So, by this process, we make two very important fuels (gas and coke) and also obtain other useful substances.

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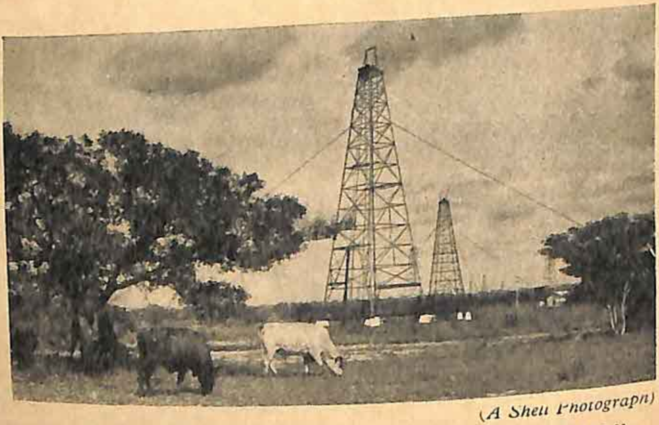
[1] You can read more about this process, and about the separation of the oils in petroleum (p. 24), in *Treasures from the Earth* in this series.

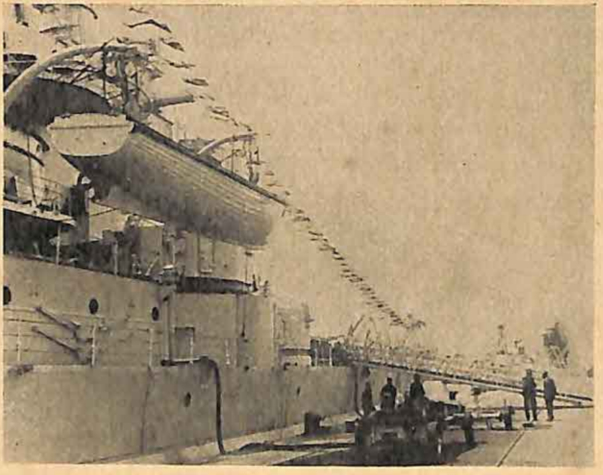
Oil is found in the ground in certain parts of the world. The impure oil is called "petroleum" (= "rock-oil"); it is a mixture of many kinds of oil. The various oils are separated and used for different purposes. The lightest oil, which turns into a vapour most easily, is petrol. This is used, of course, in motor-car and aeroplane engines. Kerosene (paraffin oil) is burned in lamps to produce light. A heavier kind of oil is called fuel-oil (see below). Other heavy oils are used for "oiling" the moving parts of machines so that they run smoothly. The heaviest parts of the petroleum consist of greases and waxes (such as candle wax).

Fuel-oil is much used as a source of heat. It does not turn into a vapour very easily but it burns well when it



(*A Shell Photograph*)

Cattle feeding peacefully by the oil-wells in an oil "field".



(*A Shell Photograph*)

Loading H.M.S. *Vanguard* with oil in the Cape Town docks during the Royal Tour of South Africa. The supply-pipe leading into the ship can be seen.

has been set alight. It is used in Diesel engines (p. 136) and, of great importance, for heating steam-engines in many large ships. It is better, in some ways, than coal for heating the water in a steam-engine. Not only is it cleaner ; it takes up less space than coal and can more easily be moved from one place to another. It is far easier, for example, to pump oil through pipes into a ship than to carry loads of solid coal, and the oil can be stored in the ship more easily.

The discovery of fire itself was of greatest importance in the history of man, but of almost equal importance was the discovery of easy ways of producing a flame and so starting a fire. We read in Chapter I how, long ago, fires were started by rubbing sticks together and so producing enough heat by friction to set light to some material which would burn easily. Then, for hundreds of years, men depended upon the little sparks which are made when certain stones are hit together. To-day, of course, we use matches. Nearly all the fires in the world, from that which burns at the end of a cigarette to that which heats the largest steam-engine, are started by matches. We can buy a box of matches so cheaply that we forget how useful they are. The match is one of Man's greatest inventions.

A match depends upon two ways of making heat: friction and chemical action. The friction produces the heat to start a chemical action and the chemical action produces a flame strong enough to set light to the little wooden stick. There are two kinds of matches: those which will strike on any rough surface and "safety"

Part of a match-making machine. In this machine the thousands of match-sticks are dipped in paraffin, the "heads" put on, and then dried.

matches which will only strike on the proper box. The head of a " strike-anywhere " match contains several substances, but the chief ones are a compound of sulphur and phosphorus (two elements which burn very well), potassium chlorate (a compound which contains much oxygen), and a little glue for holding the substances together. The mixture is quite safe at ordinary temperatures, but when it is heated by friction the chemical action begins. The sulphur and phosphorus burn (you can often smell the oxides which are formed) and the potassium chlorate provides a good supply of oxygen. The head of a safety match contains some slow burning substance (often a compound called antimony sulphide), potassium chlorate, *but no phosphorus*. There is phosphorus in the coating on the box. When the match is struck on the box, a little of the phosphorus is rubbed off. It burns, sets light to the slower burning substance, and so sets light to the stick.

There are two other well-known ways of starting a fire. A man sometimes uses a " petrol lighter " for lighting his cigarettes. This is really the modern improvement of the old process of making sparks by hitting two stones together. The " flint " (which is really a mixture of several ery uncommon metals) is rubbed by a wheel with a rough dge. The sparks set light to the petrol in the wick. The her way of starting a fire is by means of electric sparks. his way is used in a motor-car engine for " firing " the xture of petrol and air (p. 134).

Now we must read about the third way in which heat is duced. This way is by electricity. When an electric nt flows through a wire it may make the wire hot. ire in an electric lamp, for example, becomes so hot gives out light. A wire " resists " the flow of ity. The purpose of the source (such as the battery) is to drive the current along against the resistance of the wire. Some materials, such as copper and silver, give very little resistance; they let the current flow easily. Other metals, particularly certain alloys (mixtures of metals), give more resistance. We can compare the driving of electricity through a wire with the pushing of one rough thing over another. We must overcome a resistance and then heat is produced. In order to produce much heat we use strong currents or big resistances.

(*By courtesy of Birlec Ltd*).

Electric furnaces used in the glazing of pottery.

In many countries electric heating is often used in the home. Rooms are warmed by electric "fires," water is boiled by electric heaters, clothes are pressed with electric "irons," and food is cooked in electric ovens. In the factory, electric furnaces are used for producing high temperatures. Electric heating has several advantages over heating by fires. The heat can be better controlled. It can be switched on just when it is needed and switched off when it is not needed. We can produce just how much heat we need by arranging the size of the current. And electric heaters are much cleaner than fires because there is no smoke, soot, or ash.

Heat can be produced by electricity in another way. About a hundred years ago the English scientist Davy joined a carbon rod to each terminal (end) of a strong electric supply. He made the rods touch and then pulled them a short distance apart. A kind of flame was formed across the air-space between the ends of the rods. We call such a flame an electric "arc." It is very bright and very hot, in fact, the temperature at the end of one of the rods is the hottest which Man can make. Electric arcs are used in high temperature furnaces (e.g. for melting steel) and in electric welding (p. 123).

Let us now look back over the various ways in which heat is produced. The most important way is by the burning of fuels, of which wood, coal, and oil, are the chief ones. Electric heating is important too. How is electricity made? A little electricity is made by batteries but most of the electricity used in the world is produced by machines called generators. But generators must be driven by engines. They can be driven by steam-engines (in which coal or oil is burned), by motor-car engines (in which petrol is burned), or by water-power. So we see that, except for the use of water-power, electric heating chiefly depends upon coal and oil, that is, upon fuels. Heat is also produced by the friction between moving things. Most movement in the world is produced by engines (of which many depend upon fuels) and by animals (which obtain their power from food). Once more the production of heat depends upon various kinds of fuels.

From where do our fuels come? The fuel wood, of course, comes from plants; so also does the food from which we get our energy. Scientists believe that both coal and oil were formed from the remains of plants which became buried in the ground millions of years ago. So *all* our fuels come from plants. But plants can only make the carbon compounds of which they largely consist with the help of sunlight. So we can say that we depend upon the sun for our fuels.

CHAPTER V

HOW HEAT MAKES THINGS BECOME BIGGER

THE lines of a railway are made of steel rails each about 40 ft. long. The next time you are near a railway, examine the way in which the rails are fastened together. Metal bars, called fishplates, are bolted across the joins (Fig. 6) but the rails do not touch end-to-end. A small gap (or space) is left between the ends of the rails. Why is this done? If you fill a pot with water right to the top and then heat it on a fire, you find that some of the water flows over. Why is this?

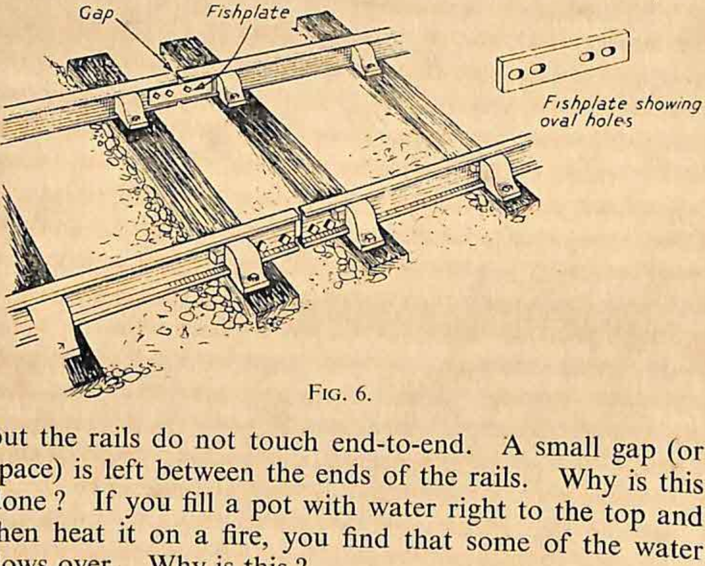


FIG. 6.

Let us try some experiments. The first one you can easily try at home. Fig. 7 shows the apparatus which you must make. AB is a piece of thin wire, about 2 ft. long, stretched between two nails in a board. The small weight W hangs from a wire joined to the middle of AB.

P is a pointer (made of cardboard) about 6 in. long. It can turn about the nail N. The wire which supports the weight is twisted round the pointer, so that it grips it, at a point C about $\frac{1}{4}$ in. from N. Heat the wire AB with a candle flame and watch the pointer. The end of the pointer slowly moves down a little way. Take away the flame so that the wire cools. The pointer goes back to its first position.

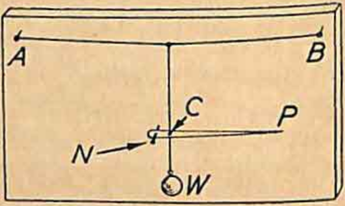


FIG. 7.

What does the movement of the pointer show? The weight W can pull the pointer down only if the wire AB drops a little at its middle. And for this to happen, *the wire AB must become a little longer.* This increase in length must have been caused by the heat of the flame. The upward movement of the pointer, after the flame has been taken away, shows that the wire AB is regaining its first length. The wire becomes shorter again when it cools.

Fig. 8 shows the apparatus which can be used for a second experiment. An iron bar, about 2 ft. long, is supported on two blocks of wood. The weight W on one end stops that end from moving. The other end rests on a thin, round rod R (such as a knitting needle). A cardboard pointer P is fixed to the rod as shown by means of the cork C. The pointer is arranged so that at first it is upright. The bar is then heated with one or two Bunsen burners. The pointer slowly moves like a hand of a clock. When the burners are taken away, so that the bar cools, the pointer slowly moves back to its first position.

The experiment proves that when the bar is heated it becomes slightly longer. One end of the bar is fixed under

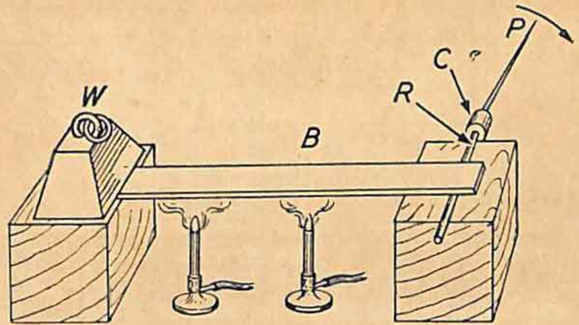


FIG. 8.

the weight; the other end moves towards the right. The bar rolls on the rod R and turns the pointer. When the bar cools, the pointer moves back. This shows that the bar returns to its first length.

All solid things increase in length when they are heated. They also become slightly thicker. We say that the solid "expands" and that "expansion" takes place. When the solid cools it becomes shorter and less thick. We say that the solid "contracts" and that "contraction" takes place. We must understand that the expansion and contraction are usually very small. We cannot often see the change in size. In both experiments we had to use a special arrangement to enable us to see it.

Although the actual expansion is very small, very strong forces are needed to stop a bar from expanding. In the same way, very strong forces are needed to stop contraction. Fig. 9 shows the apparatus which can be used to prove that a bar produces a very strong force when it tries to contract. AB is an iron bar, about 9 in. long, resting in a strong iron frame. The end B is shaped like a bolt so that the large nut N can be turned on it. Near the other end A there is a hole. A short cast-iron rod R, about

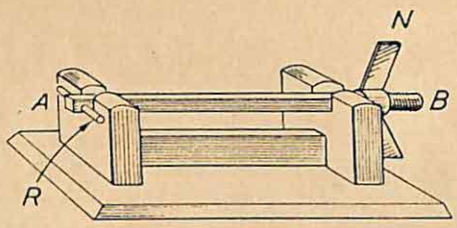


FIG. 9.

$\frac{1}{4}$ in. thick, passes through the hole as shown. The nut is turned so that the bar is firm in the frame with the rod tight against the end. The bar is then strongly heated by Bunsen burners. The bar expands. While it is being heated the nut is turned so that the bar is kept tight in the frame. The burners are taken away and the bar left to cool. It cannot contract because it is held tightly in the frame. After a few minutes the iron rod breaks. The bar produces such a strong force when it cools that the rod cannot hold against the force. Equally strong forces are produced when a bar expands.

We can now return to our problem of the railway lines. We have learned two important facts : when a bar is heated it expands and great forces are produced if this expansion cannot take place. Railway lines change very much in temperature. In the sunshine they become quite hot, they cool quickly at night, and, at some times of the year, they may be covered with snow. They therefore expand and contract. The gap is left between the ends of rails so that each rail has space in which to expand. If no gaps are left the strong forces which are set up would bend the rails out of shape. But, you may say, the rails are not free to expand ; the fishplates hold them. The holes in the fish-plates, through which the bolts pass, are oval (longshaped) and those in the rails are round (Fig. 6).

When the rails expand and contract, they can slide along slightly because the bolts can move across the oval holes.

Suppose we have two bars of the same length but made of different materials (such as iron and copper) and we make them equally hot. Will they expand by the same amount? You can try an experiment to find out. Fig. 10 a shows two metal strips, one of steel and one of brass, firmly fastened together with nuts and bolts.[1] It is a "bimetallic strip," that is, it is made of two metals (*bi* = two). The strip is straight at ordinary temperatures. It is heated in a gas flame or in the fire. When it is hot it becomes curved with the brass on the outside of the curve (Fig. 10 b). Now look at Fig. 10 c. It shows parts of two circles (SS and BB). The part BB, which is on the outside of the curve, is longer than the part SS. The bimetallic strip is curved when it is hot. The strip on the outside of the curve (brass) is therefore longer than the strip on the inside (steel). So we learn that brass expands

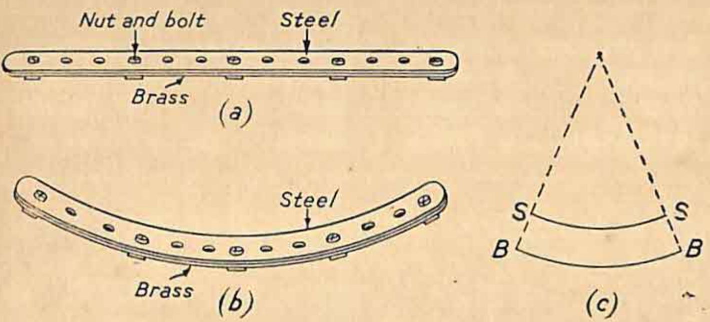


FIG. 10.

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[1] You can use a "Meccano" strip (steel) and cut a similar strip from a sheet of brass.

more than steel. In a similar way, brass contracts more than steel if it is cooled. What would happen to a bimetallic strip if you lay it on a block of ice or bury it in snow?

The actual amount of the expansion (or contraction) depends on the length of the bar, the material of which it is made, and the rise (or fall) in temperature. The table gives the "expanding powers" of some common materials.

Iron and Steel	0·000012	Glass (ordinary)	0·0000089
Copper	0·000017	Pyrex glass	0·0000032
Brass	0·000019	Invar	0·0000009
Aluminium	0·000025	Stone (about)	0·000003

Look at the figure for iron and steel (0·000012). It tells us that if we have an iron bar 1 ft. long, and we heat it through 1° Centigrade,[1] it expands by 0·000012 ft. So also, if we have 1 cm. (or 1 in., or 1 mile, and so on) of iron, and we heat it through 1 degree, it expands by 0·000012 cm. (or in., or mile, etc.). In some science books these figures are called "coefficients of linear expansion." This is a long name for something which is quite simple. A coefficient is a number by which you multiply, linear means lengthwise, and expansion you already know.

Now here is a little problem. An iron bar, forming part of a railway line, is 40 feet long at 0° C. (freezing point of water). How much longer will it be on a summer day when the temperature is 25° C.?

---

[1] Temperatures are measured in degrees Centigrade or in degrees Fahrenheit. (If you do not already understand them do not worry; they are explained in detail in Chapter VII.) The figures in the table are those for degrees Centigrade.

We know that :—

1 ft. of iron, when heated 1 degree, expands by 0·000012 ft.
But our bar is 40 ft. long; it expands 40 times as much.
So 40 ft. of iron, when heated 1 degree, expands by
  0·000012 × 40 ft.
But the bar is heated through 25 degrees, that is, 25
  times as much.
40 ft. of iron, when heated 25 degrees, expands by
  0·000012 × 40 × 25 ft.
This, as you can work out, is 0·012 feet, or about $\frac{1}{7}$ inch.

Now we must return to our other problem. Why does the water overflow from a full pot when it is heated ? We can easily guess the answer. Water expands when it is heated. If you fill a jar with hot water and leave it to cool, you find that there is a space at the top of the jar (We sometimes notice this when we fill a jar with hot jam or a bottle with hot milk.) A liquid contracts when it cools.

To study the expansion and contraction of a liquid more carefully, we can use the apparatus shown in Fig. 11. The round glass vessel is called a flask. The flask is completely filled with water and a little dye added. The long glass tube just passes through the cork. The cork is pressed into the top of the flask so that there is no air in the flask and the water rises

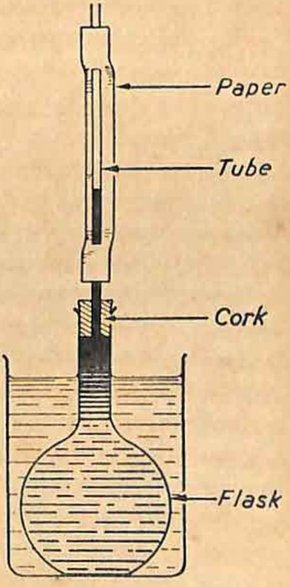


FIG. 11.

a little way up the tube. A strip of paper can be fixed to the tube so that you can see the level of the water more clearly. The flask is stood in a larger container of water and heated (e.g. by a Bunsen burner). As the water in the flask becomes hot the level gradually rises up the tube and may even reach the top. The water expands. When the water is left to cool, the level gradually falls and, if no water was lost out at the top, it comes down to its first position. The water contracts when it cools.

This experiment shows us that water expands when it is heated and contracts when it cools, and, further, it shows us that water expands far more easily than a solid. The water in the flask was heated, not by a burner, but by hot water, and yet the expansion was enough for us to see. (The narrow tube, of course, enabled us to see the expansion more easily.) Many other liquids expand even more easily than water. Alcohol, for example, expands about 2½ times as much as water.

Gases, such as air, also expand when they are heated. Take a small "empty" medicine bottle and hold it with the neck just dipping into some water in a dish. Cover the bottle as far as possible with your warm hands. One or two bubbles of air escape from the bottle. The air in the bottle expands. We can try a better experiment with the apparatus shown in Fig. 12. It consists of a flask fitted with a cork and a glass tube. The flask is "empty," that is, it contains some air. The apparatus is supported so that the

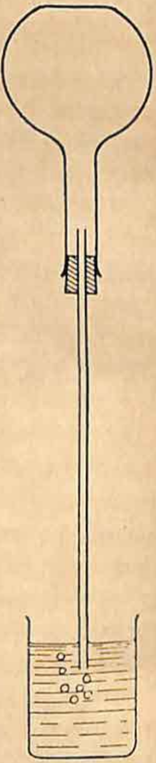


FIG. 12.

end of the tube dips into some water. When the flask is warmed with the hands, bubbles of air escape from the tube. The air expands. When the hands are taken away so that the flask cools, the water rises a little way up the tube. The air contracts. It is important to notice that in this experiment we use neither a burner nor even hot water ; the warmth of the hands is enough to make the air expand. Air, therefore, expands and contracts more easily than a liquid or a solid. If we soak a rag in hot water and wrap it round the flask, bubbles of air escape very quickly, and if we then pour cold water on the flask, water rushes up the tube and enters the flask.

Suppose we have 1 cubic foot of ordinary air and we heat it from 0° C. (freezing point of water) to 100° C. (boiling point of water). If it is free to expand it becomes rather more than $1\frac{1}{3}$ cubic ft. You will be surprised to learn that 1 cubic ft. of any other gas (e.g. nitrogen, hydrogen), when heated in the same way, expands by this same amount. All gases expand equally. Very often a gas is inside a closed container and is not free to expand. Then its pressure increases when it is heated. It presses more strongly on the inside of the container and may even break it.

CHAPTER VI

EXPANSION AND CONTRACTION IN EVERYDAY THINGS

EXPANSION and contraction, about which we learned in the last chapter, are of great importance to us in our daily lives. Sometimes we make good use of them (and of the big forces which they produce) but more often they cause much trouble. We must remember that all things expand if they become hot and, if there is no space in which they can expand, the strong forces which are produced may cause damage. The iron bars of a fire-place or of an oven must fit loosely so they have space in which to expand when they become hot. The engine of a motor-car must be cooled so that the pistons do not stick in the cylinders. Pipes which carry steam or hot water must have space in which to expand. If telephone wires are put up in the summer they must be hung loosely so that they can contract in cold weather. If you pour some hot water into a thick, cold drinking-glass you may crack it. The inside of the glass becomes hot and tries to expand. Heat does not pass very quickly through the glass and so the outside remains cool and does not expand. The glass therefore cracks. Special kinds of glass have been invented which can be heated and cooled without risk of breaking. One of these kinds is called Pyrex glass. Notice, in the table on p. 36, that it has a very small coefficient of expansion. Pyrex vessels are often used for cooking.

A clock is often controlled by a pendulum. The pendulum swings backwards and forwards steadily and makes the hands turn steadily. If the pendulum expands (becomes longer) it swings more slowly and the clock "loses"; if the pendulum contracts (becomes shorter) it swings more quickly and the clock "gains." This is one reason why cheap clocks sometimes keep bad time. In an old clock you may find a complicated pendulum (in the form of a framework) made so that its length does not change even though its temperature may change. In a modern clock the pendulum is usually made of "invar." This is an alloy of steel and nickel. It has a very small coefficient of expansion (see the table on p. 36). An invar pendulum changes so little in length with ordinary changes of temperature that the clock keeps good time. You may be interested to know why the alloy is called "invar." The length of an invar bar is almost *invar*iable, that is, it does not vary or change.

A pocket watch is controlled by a "balance wheel" (Fig. 13). The wheel turns steadily backwards and forwards on the "hair-spring" and controls the speed at which the hands turn. You can usually see the balance wheel and hair-spring if you open the back of a watch.

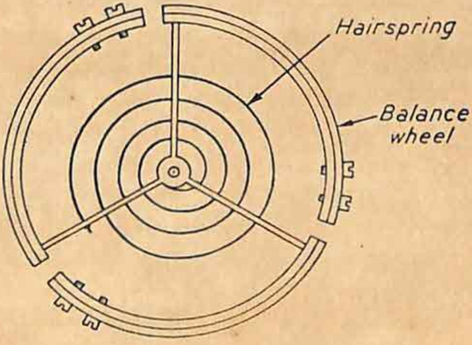


FIG. 13.

In hot weather the balance wheel expands and the hair-spring becomes weaker. For both of these reasons the balance wheel would turn more slowly and the watch would "lose." An invar balance wheel would not expand but the watch would still lose because of the loss in strength of the hair-spring. In a good watch the balance wheel is made in 2 or 3 parts each with a spoke (see drawing). The rim (edge) is a bimetallic strip of steel and brass. A rise in temperature causes the spokes to become longer but the pieces of the rim curve inwards. This change of shape of the wheel causes it to turn at its proper speed although the spokes are longer and the hair-spring weaker. The watch therefore keeps good time. Look in your watch and see if the balance wheel is made in this way.

Metals, particularly, heat and cool quickly (p. 69). A large steel roof, as on some railway stations, expands and contracts with the changes of temperature. If the roof is firmly fixed to the walls on each side it would pull them in and out. So only one side of the roof is fixed; the other side is supported in such a way that the roof can move slightly without moving the wall. Fig. 14 shows two ways in which the roof can be supported: (a) is called a

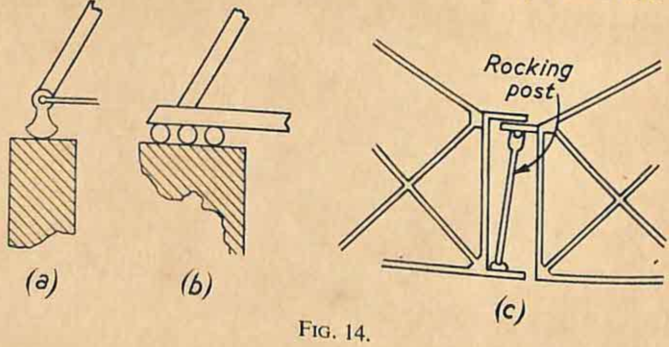
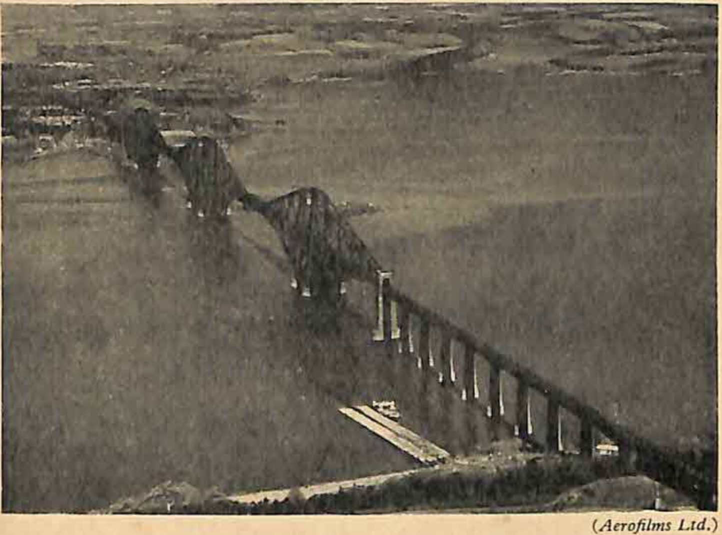


FIG. 14.

"rocker" bearing and (b) a "roller" bearing. (A bearing is a support which allows movement.) You can easily see how each of these allows a slight movement of the roof.



(*Aerofilms Ltd.*)

The Forth Bridge, Scotland. Its total length is 1½ miles. About 6 ft. is allowed for the expansion of the metal parts.

It is important that a metal bridge shall be able to expand and contract without bending and breaking. The Forth Bridge in Scotland, for example, is a mile long (without the parts leading to it) and a total space of 6 feet is provided for expansion. Fig. 15 shows the chief places where the spaces are provided. The only parts of the bridge which are fixed are those marked F. At the ends A and D the bridge rests on roller bearings similar to those just described. At B and C there are "rocking posts." Fig. 14 c shows a rocking post. The post can move so that it is not always upright. It joins two parts of the bridge but lets them move sideways.

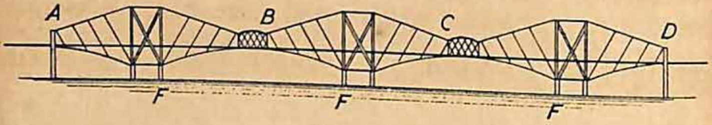


FIG. 15.

By now you may be thinking that expansion and contraction always cause trouble or danger. It is true that we often have to provide space for expansion to take place. But good use is also made of expansion and contraction, and of the strong forces which they produce. The metal sheets of a steam-engine boiler and of the sides of a big ship are fastened together with "rivets." Fig. 16 shows how a rivet is used. The rivet, which is like a short, thick nail, is put through a hole in the two sheets; the end of the rivet is then hammered flat. Rivets are put in *red-hot* and hammered flat before they cool very much. Then they cool and contract and hold the metal sheets firmly together.

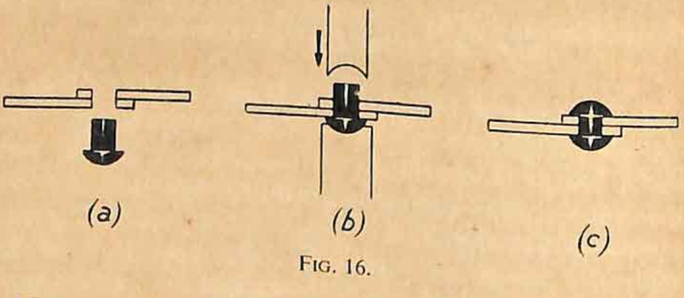
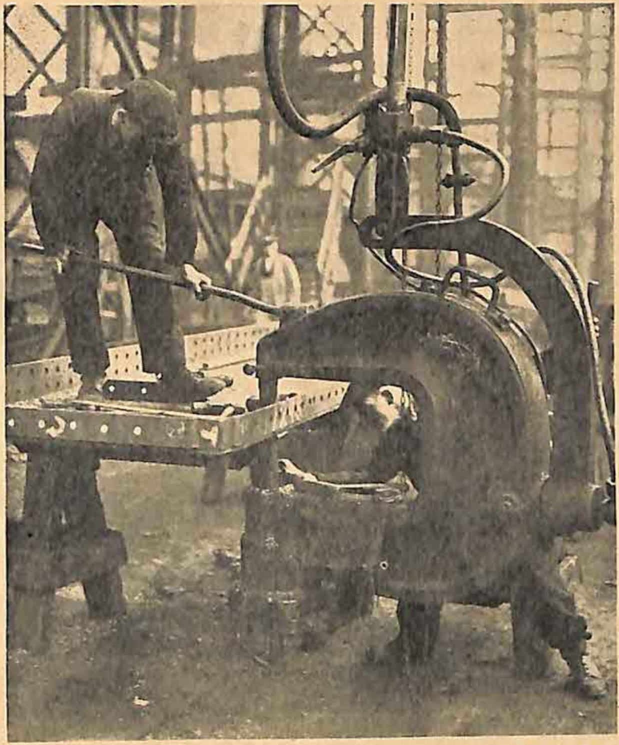


FIG. 16.

Many wooden wheels, such as those of a cart, have iron rims. The rim is made slightly too small to fit on the wheel. It is then heated so that it expands and can be



(*Fox Photos Ltd.*)

Using a hydraulic (water-pressure) machine to put in rivets. This picture was taken in a ship-building yard.

slipped over the wheel. When it cools and contracts it grips the wheel tightly. The rims of wheels of railway engines and trucks are put on in a similar way.

Bimetallic strips have many uses. We saw one use in the balance wheel of a watch. Fig. 17 shows how a bimetallic strip can be used to switch on an electric current. B is the strip. The wires W_1 and W_2 are joined to the electric battery but the current does not flow because the wires are not joined to each other. If the switch is put in a hot place, the strip bends (as shown by the broken lines) and touches the screw S. The wires are now joined and a current flows. Such a switch is sometimes used in the chimney of a furnace. It can switch on a current and give a warning (e.g. by ringing a bell) when the temperature is too hot. Can you suggest how a similar switch could be made to turn *off* a current when the temperature rises above a certain value? Such a switch is sometimes used to control the electric heating of a water container or an oven.

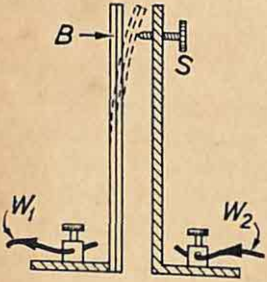
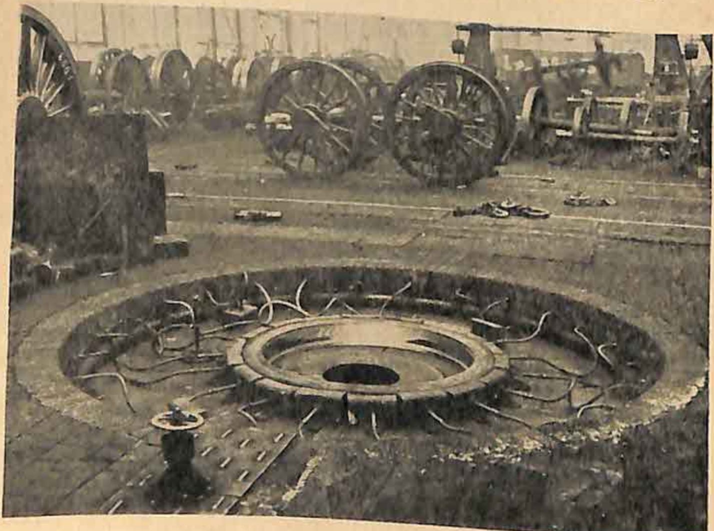


FIG. 17.



(*By courtesy of British Railways*)

"Tyre" furnace in a railway wheel-shop. The rim is made hot before it is fitted on the wheel; when it cools it grips the wheel tightly.

The expansion of a liquid is sometimes inconvenient, as when water in a pot overflows, but, in our daily lives, it causes less trouble than the expansion of a solid. The expansion is useful in one very important way. The ordinary kind of thermometer, as used for measuring temperatures, depends upon the expansion of a liquid. We shall read about it in the next chapter.

We have learned that a liquid contracts when it cools. There is one exception to this, and, strangely, the liquid is the one we know best—water. If we cool some water down to the ordinary temperature of the air, it certainly contracts, as we found in our experiment. Suppose we are able to cool it further. If we make it cold enough (0° C.) it freezes to form solid ice. *But, during the last small part of the cooling*, actually from 4° C. to 0° C., *the water expands.* In a similar way, if we heat some water from 0° C. it contracts at first, and then, after 4° C., expands like other liquids.

This unusual result explains what happens when water (e.g. in ponds and lakes) freezes in very cold weather. The water cools chiefly at the top where it meets the cold air. At first the cooled water contracts, becomes denser (heavier), and sinks to the bottom, while warmer water from the bottom rises to takes its place. After a time, when all the water has cooled to 4° C., the water at the top is cooled further. *This water now expands.* It becomes less dense (lighter) and so stays at the top. The very coldest water, therefore, is at the top and *the ice forms at the top.* Further, as ice floats (p. 78), it stays at the top. The sheet of ice may gradually become thicker, but it forms a kind of cover over the water, and it is very rare for the water to freeze right down to the bottom. Fish and other water-creatures can live in the water below the sheet of ice. If the ice formed at the bottom first and gradually grew upwards, the fish would be forced to the top, and, if all the water turned to ice, they would not be able to live.

Except for the air around us, the gases which we usually meet in our daily lives are in closed containers. If the gas is heated it presses more strongly on the sides of its container. If you leave your bicycle standing for several hours in the sunshine the tyres may burst. The air in the tyres expands with the heat and presses more and more strongly until the tyres cannot hold it. In a similar way, potatoes usually burst if they are baked with their skins on. We often first prick holes in the skins so that the air can escape when it expands. You can sometimes make a rubber ball which has a dent in it return to its proper shape by warming it in front of a fire. The air inside the ball expands and pushes out the dent.

The force of expansion of hot gases is put to good use in a motor-car engine. The very quick burning of the petrol produces a lot of hot gases in the small space above the piston. The gases push the piston and so work the engine (p. 134).

When a gas expands it becomes less dense (lighter). Hot air, therefore, rises from a fire and fresh, cold air flows in to take its place. This inward flow of fresh air helps the fire to burn. In a similar, but very much bigger way, the winds are caused by the unequal heating of different parts of the Earth.

CHAPTER VII

HOW TEMPERATURES ARE MEASURED

WHEN we put a pot of water on the fire, heat passes in so that the water gradually becomes hotter. We use the word "temperature" when we wish to speak of the "hotness" of anything. So the question "What is its temperature?" is another way of asking "How hot is it?" Temperatures can be described very roughly by using words such as cold, cool, warm, fairly hot, and so on, but, in science, we need more exact ways of describing temperatures.

For thousands of years men depended upon their feelings to judge how hot things were. We can tell, for example, whether some water in a dish is hot or cold by putting our fingers in it. But it is very rough to depend upon feelings when judging temperatures, indeed our judgment may be quite wrong. There is a well-known experiment for showing that we cannot depend upon our feelings of hot and cold. You need three dishes of water. The water in the first is cold, that in the second hot, and that in the third warm (i.e. an equal mixture of hot and cold). Hold your left hand for half a minute in the cold water and, at the same time, your right hand in the hot water. Then put both hands in the warm water. To your left hand this water seems fairly warm and to your right hand it seems fairly cold. Which hand can you depend upon? The answer is Neither!

Clearly we need an instrument for measuring temperatures accurately. Such an instrument is called a thermometer. In all kinds of thermometers, as we shall see, heat causes some change (such as expansion) which we can see and measure.

The most common kind of thermometer depends upon the expansion and contraction of a liquid. Turn back to Fig. 11 (p. 37). When the liquid in the flask is heated the level of the liquid in the tube rises. When the liquid cools, the level goes down. So the height of the liquid in the tube shows how hot the liquid is. We *might* use such a piece of apparatus as a thermometer, by holding the flask in the thing whose temperature we want to measure, but it would not be very convenient. The apparatus would be big and awkward to use and it would take a long time to heat up to the proper temperature.

The ordinary "mercury in glass" thermometer is like a small model of this apparatus. Try to get a thermometer and study its parts. In Fig. 18 a thermometer is drawn by the side of the apparatus so that you can compare them. Notice the ways in which they are alike. The "bulb" of the thermometer is like the flask and the "stem" is like the tube, but the thermometer is made all in one piece. Because the bulb is much smaller than the flask the "bore" of the stem (that is, the width of the hole inside it) must be much less than that of the tube. The bulb is made of thin glass so that heat can pass into the mercury quickly. The mercury, of course, takes the place of the coloured water. Notice that the top of the stem is closed. When a thermometer is made, the stem is filled with hot mercury

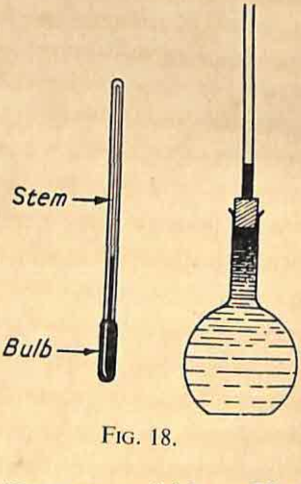


FIG. 18.

and the top then closed. When the mercury cools and contracts, it leaves an empty space at the top.

When we put the bulb of the thermometer into something which is hot, the mercury expands and the level in the stem rises. When we take the bulb out, or put it into something which is cold, the mercury contracts and the level in the stem falls. So the level of the mercury in the stem shows the temperature.

But we do not want a thermometer just to tell us when things are hot or cold ; we want to be able to *measure* a temperature, that is, to be able to give it a number. We can make marks on the stem, and give them numbers, so that we can describe a temperature by saying against which number the mercury stands. But if we want other people to be able to understand what our numbers mean, and if we want to be able to understand other people's numbers, all thermometers must be numbered alike. Imagine we are making a thermometer. We have made the glass part and have put the mercury inside. We now need to put the numbers on the stem and to make our thermometer agree with other thermometers. Where shall we start the marks ? How far apart shall we make them ? What numbers shall we give to them ?

Pure ice always melts at the same temperature. It does not matter whether a man is making a thermometer in England, in Africa, or anywhere else ; the temperature of melting ice is always the same. This temperature is used as the starting point of the numbers on the stem. We put the bulb of the thermometer we are making in a dish of melting ice and make a mark on the stem at the level where the mercury stands. This mark is called the " lower fixed point." We sometimes call this temperature " the freezing point " because it is is also the temperature at which pure water freezes.

Pure water boils at a certain steady temperature.[1] This is a second temperature on which we can depend. We put the thermometer in some pure, boiling water and mark the level to which the mercury rises in the stem. (As the water may not be quite pure, it is more accurate to surround the thermometer with steam which comes from boiling water.) This mark is called the "upper fixed point." It is also known as the boiling point (of water).

When the fixed points have been marked on the stem we have to decide what numbers we shall give to them. Several sets of numbers have been suggested at different times but only two sets of numbers are commonly used now. (And it would be better if there were only one!) The simplest set of numbers is called the Centigrade scale. The lower fixed point (freezing point) is given the number 0 and the upper fixed point (the boiling point) is given the number 100. The space between the marks is divided into 100 equal parts or "steps." Each "step" is a Centigrade degree. (Latin *centum* = 100, *gradus* = step.) We can describe a temperature by saying against which number the mercury stands. Thus the temperature of the air in a room may be 20 degrees on the Centigrade scale, or, as we more usually write it, 20° C. (Notice the little circle which means degrees.) The Centigrade scale is used in France, and, because it is simple, by scientists all over the world.

Another scale, which is chiefly used in England and America, was suggested by an instrument-maker called Fahrenheit. He wanted to make 0° the coldest temperature which he could reach (obtained by mixing ice and salt) and 96 the temperature of the human body.[1] To fit in with this set of numbers, the freezing point is 32° and the boiling point 212°. Notice that there are 180 " steps " between the fixed points on this scale. Fig. 19 shows a Centigrade thermometer and a Fahrenheit thermometer side by side. You can compare the two sets of numbers.

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[1] Actually the temperature changes a little according to the pressure of the air (p. 85). A correction is made for this when making a thermometer.

When we state a temperature we must be sure to state the scale which we are using. You would not mind washing your hands in some water at 100° F. but you would not like to put your hands in some water at 100° C. There are, of course, temperatures hotter than the boiling point of water. The metal lead, for example, melts at 327° C. and we can have temperatures much hotter than this. We can also have temperatures colder than 0° C. Below 0, on either kind of thermometer, we use the numbers -1, -2, -3, and so on. The table on p. 54 shows some common temperatures on the two thermometers.

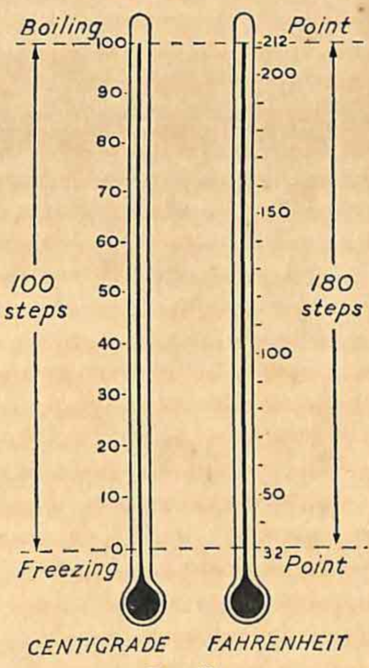

FIG. 19.

It is unfortunate that two kinds of temperature scale are in common use. Sometimes we know a temperature

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[1] The temperature of the body on this scale is now known to be 98·4° F.

	Centigrade	Fahrenheit
Boiling point of water	100°	212°
Alcohol boils	78°	172°
Healthy human body	37°	98°
Hot day in West Africa (about)	35°	95°
Summer day in England (about)	25°	77°
Water freezes, ice melts	0°	32°
Coldest ever in London (1838)	−20°	−4°

on one scale and wish to know what it is on the other scale. We can change from one scale to the other by making calculations, but an easier way is by making a graph (see Fig. 20). On a piece of paper ruled out in squares, draw an upright line at the left hand edge and mark off on it a suitable scale to represent Fahrenheit degrees. Draw a line across the bottom and mark off on it a scale to represent Centigrade degrees. Now we *know* two temperatures on both scales: 0° C., 32° F., and 100° C., 212° F. Mark the point A opposite the 0 mark on the C. scale and on the 32 mark of the F. scale. Mark the point B opposite the 100 mark on the C. scale and 212 mark on the F. scale. Join these points by a straight line. Then we can use this graph to read off any temperatures (between the fixed points) which we need. Suppose, for example, we want to know what temperature on the F. scale agrees with 60° C.. We find the point X which is opposite the 60° C. mark. This point, we find, is opposite 140 on the F. scale. So 140° F. is the same temperature as 60° C. How could you improve your graph so that you could use it for temperatures above the boiling point or below the freezing point?

A doctor often uses a special kind of thermometer. The temperature of the human body is very steady. If

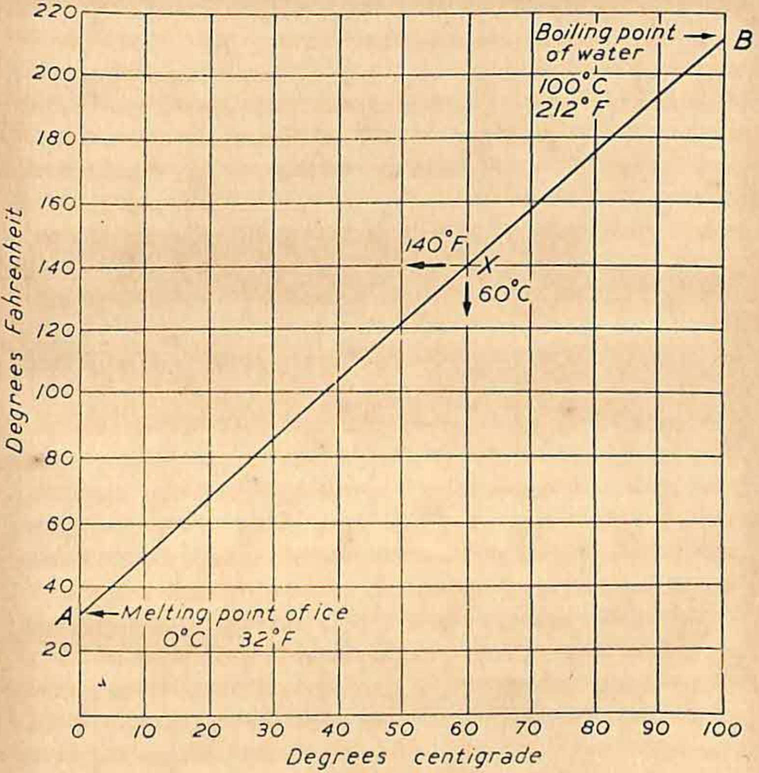


FIG. 20.

the body is healthy the " normal " (usual) temperature is 98·4° F. If the temperature changes by even a degree or two it shows that the person is unwell. Fig. 21 shows a doctor's thermometer. The scale reaches from 95° F. to 110° F. (No *living* person would have a temperature outside this range !) Each degree is divided into fifths. Near the bulb there is a bend in the bore, or, sometimes, a very narrow part. The doctor puts the bulb in the person's mouth (for example) and the mercury expands. The mercury can push its way past the bend. After a minute or two the doctor takes the thermometer out. The mercury in the bulb contracts but it cannot *pull* back the mercury in the stem. The mercury stays in the stem and so shows the highest temperature reached. The mercury must be shaken back past the bend before the thermometer is used again.

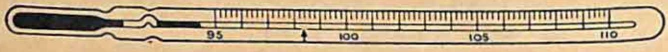


FIG. 21.

In our ordinary lives we do not often need to measure temperatures which are much below the freezing point or above the boiling point. We know, of course, that a fire is much hotter. Perhaps the hottest thing which we usually meet is the white-hot wire inside an electric lamp. We may wonder what is the highest temperature which Man has produced, and what is the lowest.

Scientists believe that it is impossible to make a temperature lower than − 273° C. At this temperature, they believe, a thing would have no heat at all. They call this temperature Absolute Zero. Temperatures have been produced which are less than one degree above absolute zero. Air becomes liquid at about − 180° C. The highest temperature which Man has been able to make is about 3,500° C. This is the temperature of an electric arc (p. 29). It is very hard to realise what these very cold and very hot temperatures really mean. Fig. 22 helps you to understand them. Notice that the range of temperatures with which we are most familiar is only a very small part of the whole range which Man can produce.

The ordinary mercury-in-glass thermometer is quite useless for measuring very cold or very hot temperatures. At low temperatures the mercury would freeze; at high temperatures the mercury would boil and the glass would melt. The ordinary thermometer depends upon the expansion of a liquid. There are other thermometers which depend upon other effects of heat. There is a very accurate thermometer which depends upon the expansion of a gas (such as air, or hydrogen). This kind of thermometer, however, is big and awkward to use. Another kind depends upon the fact that the electrical resistance of a wire (the opposition it gives to the flow of a current) increases when the temperature is raised. Such thermometers are very useful, especially as they can be used for both high and low temperatures. Most of the thermometers which are used in factories, for measuring the temperature of furnaces, melted metal, gases coming from engines, and so on, depend upon yet another effect of heat. Let us examine this effect more closely.

In Fig. 23 wires of two different metals, such as copper and iron, are twisted together and the free ends joined to

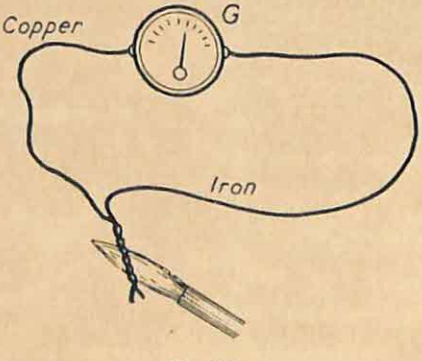
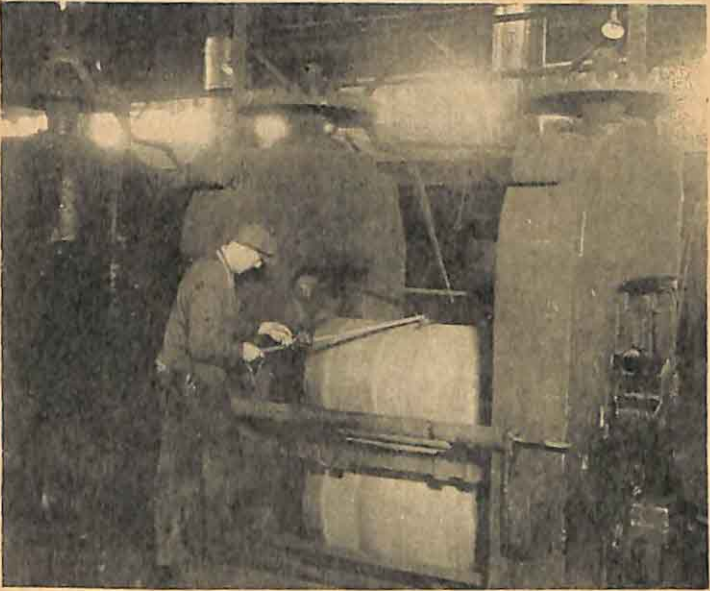


FIG. 23.

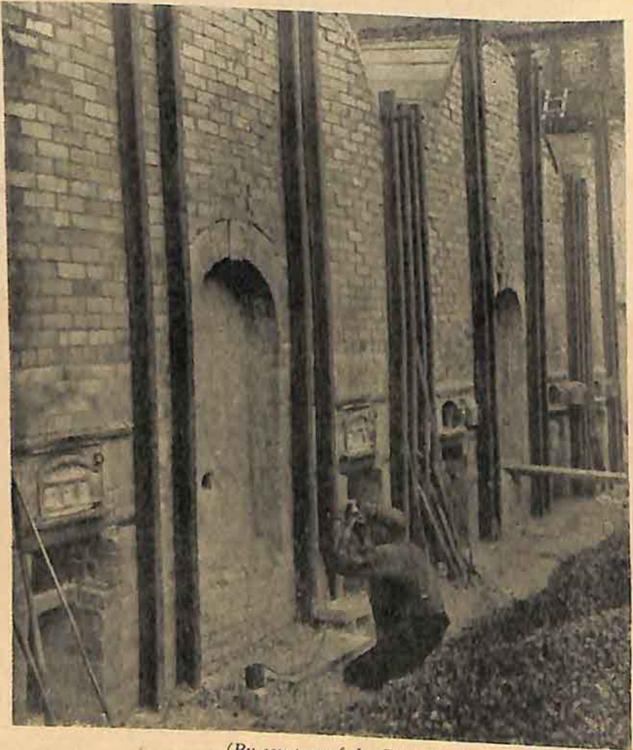


(By courtesy of the Cambridge Instrument Co. Ltd.)

Taking the temperature of the hot rollers in a steel-rolling machine with a thermo-electric thermometer. Notice the galvanometer in the man's hand.

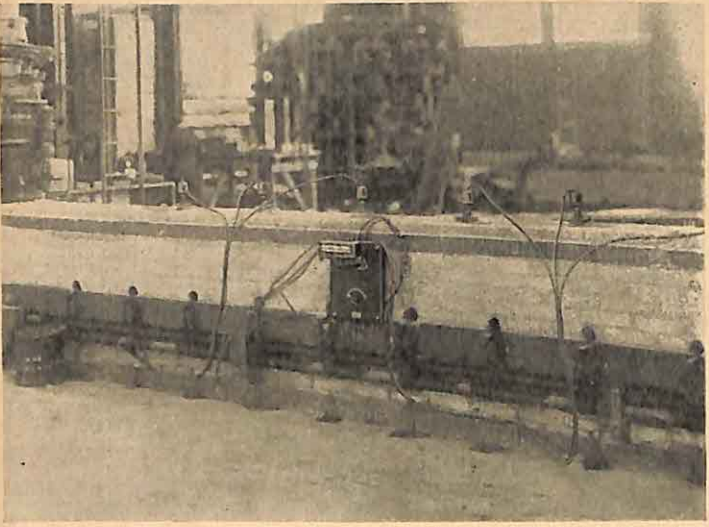
a "galvanometer" G. This is an instrument for measuring small electric currents. If we heat the join of the wires, the galvanometer shows that a current flows. We have, in fact, produced electricity from heat. (The current, however, is small.) The strength of the current depends upon the temperature of the wires at the join. So we can use the strength of the current, as shown by the galvanometer, to tell us the temperature of the join. We can actually mark degrees of temperature on the scale of the galvanometer. The whole piece of apparatus is then a thermometer. This effect is called the "thermo-electric" effect and the twisted wires, when used for measuring temperatures, form a "thermo-couple." There are some pictures of thermo-electric thermometers in use on pages 59 and 61.

For very high temperatures yet another kind of thermometer must be used. The picture below shows a man using a "disappearing filament" thermometer. The thermometer contains an electric lamp. The man can change the brightness of the lamp by changing the strength



(By courtesy of the Cambridge Instrument Co. Ltd.)

Using a disappearing filament thermometer to take the temperature of a brick kiln (oven).



(By courtesy of the Cambridge Instrument Co. Ltd.)

Thermo-electric thermometers in an oven used in glass-making.

of the current. He looks through the instrument at the fire in the furnace. (Usually there is a hole in the side of the furnace for the purpose.) He changes the brightness of the lamp until the filament (the wire inside) is just as bright as the fire. The filament then seems to disappear. From the strength of the current flowing through the lamp he can tell the temperature of the fire.

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Chapter VIII

HEAT MEASUREMENTS

When some coal burns in a fire it gives out a certain amount of heat. Some kinds of coal are better than others. How can we measure the amount of heat which is given out when a fuel burns? When some water is put in a pot on the fire it becomes hot. Heat has passed from the fire, through the pot, into the water. How can we measure the amount of heat which has passed into the water? Heat is not a substance which we can see. It does not take up any space; it has no weight. We cannot measure it in pounds, or feet, or gallons. We can only measure it by measuring something which it can do.

The most obvious thing which heat can do is to make water hot. But we cannot measure an amount of heat merely by finding how hot it makes some water. Suppose you have two tins, of exactly the same shape and size, and fill one with water but only half-fill the other. If you heat each for the same time over the same size flame, you put the same amount of heat into each. But do you produce the same rise in temperature in each? No. The smaller amount of water becomes hotter. The amount of *heat* given to each is the same but the rise in *temperature* is different.

It is not always easy at first to understand this difference between an amount of heat and the rise in temperature which it produces. Let us try to make it clearer. Fig. 24 shows two jars. One (a) is a narrow jar, the other (b) is a wider jar. Suppose we put an equal amount of water into each. The levels in the two jars are not the same. The level is higher in the narrow jar (a). In a similar way, if we give equal amounts of heat to a pin and to a 6-feet steel bar (e.g. by heating each with a lighted match) their temperatures rise by different amounts. The pin might become nearly red-hot but the temperature of the bar does not rise enough for you to notice.

People often use the words "temperature" and "heat" wrongly in ordinary speaking. They tend to speak, for example, of the heat of an oven when they mean its temperature. It is not difficult to measure the temperature of an oven (with a suitable thermometer) but it is quite a different problem to measure how much heat there is in the oven.

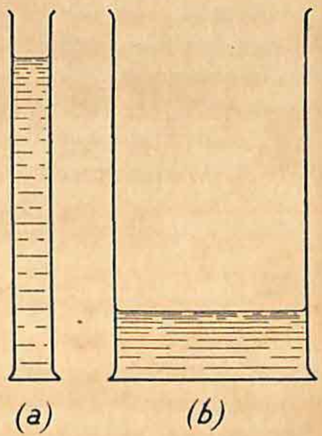

FIG. 24.

Consider the jars again. If we use jars of the same size (i.e. same width), and put the same amount of water into each, the levels will be the same. If we put twice as much water into one, the depth will be twice as great. The depth, in fact, shows the amount of water, but only if we always use jars of a certain, fixed width. If, in a similar way, we choose a *certain, fixed weight* of water, equal amounts of heat will produce equal rises in temperature. We can measure an amount of heat by finding the rise in temperature which it produces.

Scientists have agreed to measure an amount of heat by finding the rise in temperature which it produces in *one* *gramme* of water. They give a special name to the amount of heat which makes *one gramme* of water hotter by *one degree Centigrade*. It is called the CALORIE. We measure an amount of heat in calories.

Here is a little problem: 1,000 grammes of water are heated on a fire from 20° C. to 100° C. How much heat goes into the water?

We know that:—

1 gramme of water, when made 1 degree hotter, receives 1 calorie.

In our problem we have 1,000 grammes. This, clearly, needs 1,000 times as much heat. So—

1,000 grammes, when made 1 degree hotter, receive 1,000 calories.

Next, the water is heated, not through one degree, but from 20° C. to 100° C., that is, through 80 degrees. This requires 80 times as much heat. So—

1,000 grammes, when made 80 degrees hotter, receive 80,000 calories.

You can probably see a short way of doing problems like these. We get the answer by multiplying together the weight of water (in grammes) and the rise of temperature (in degrees Centigrade). In a similar way we can find out the amount of heat given out, or lost, when a hot thing cools. We multiply together the weight of water and the fall in temperature.

Although in science we measure weights in grammes and temperatures in degrees Centigrade, in England and some other countries we more usually measure weights in pounds and temperatures in degrees Fahrenheit. So there is a special British unit for measuring heat. It is the amount of heat which raises the temperature of one *pound* of water by one degree *Fahrenheit*. We call it the British Thermal Unit (often written B.Th.U.). We can work out an amount of heat in B.Th.U.'s by multiplying together the weight of water in pounds by the rise (or fall) of temperature in degrees Fahrenheit.

We usually buy fuels, such as coal, oil, and coal-gas, to give us heat. An ordinary person may not need to know exactly the amount of heat he gets from each pound of coal which he buys, but he likes to know if the coal will give plenty of heat. An engineer who, for example, uses coal in a steam-engine in a factory, needs to know exactly how much heat he will get from his coal. If the coal has poor heating-power he will have to use more of it in the engine—and he will expect to be able to buy the poorer coal more cheaply.

Fig. 25 shows the kind of apparatus which is commonly used for finding the heating-power of a fuel such as coal. The chief part is a strong steel container C. It is made of two halves which can be tightly fastened together. There is a little cup in the middle of the container. A small amount of the coal is put in this cup, the two halves are fastened together, and oxygen is pumped in. The container is stood inside a larger vessel V which is then filled with a measured weight of water. T is a thermometer for measuring the temperature of the water and S

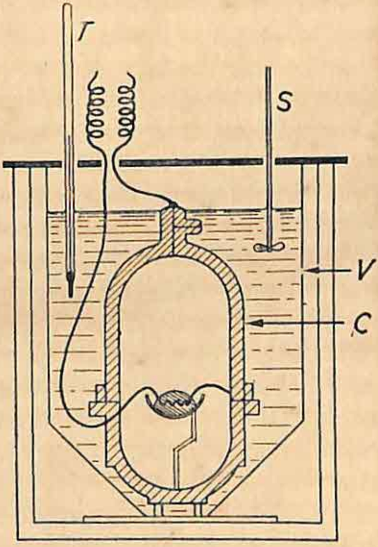

FIG. 25.

a stirrer (drawn very simply). The coal is set alight by sending an electric current through a wire which is partly buried in it. The heat from the coal passes into the water. From the rise in temperature and the weight of the water, the amount of heat given out by the coal can be worked out.

The heating-power of a pound of coal is 10,000–14,000 B.Th.U.'s. A pound of dry wood gives about 8,000 B.Th.U.'s and a pound of fuel oil 17,000–19,000 B.Th.U.'s. Coal-gas gives about 500 B.Th.U.'s for each cubic foot. We usually buy coal by weight, that is, we pay so much for a ton of coal, but we buy gas according to the amount of heat which it can give. In England the price is about a shilling for 100,000 B.Th.U.'s.[1]

Some of the foods which we eat are really fuels. They "burn" very slowly inside the body (not with smoke and flame !) and give us energy. This energy keeps us warm and gives us the power to move about. Most of our foods are mixtures of several kinds of substances, but some consist chiefly of one kind. Substances like sugar and starch are called carbohydrates. Bread and potatoes contain carbohydrates. Butter consists chiefly of fat. Carbohydrates and fats are the chief energy-giving substances in food. Meat and eggs contain substances called proteins. Proteins give us some energy but they are also used for body-building.

Carbohydrates and fats produce the same amount of heat in the body as they do when they burn in the ordinary way. We can therefore measure the heating-power of a food in much the same way as we measure the heating-power of a fuel. As a calorie is a small amount of heat we usually state the heating-power of a food in Calories spelt with a capital C (also called a Big calorie and a Kilocalorie). A Calorie is 1,000 ordinary calories.

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[1] 100,000 B.Th.U.'s is sometimes called a therm.

The table below shows the heating-power of different kinds of food. Notice the high values for bread and sugar (carbohydrates) and butter (fat). Potatoes contain a lot of water and so are less useful. Meat and eggs (containing proteins) have small heating-powers. Scientists have worked out that an ordinary man needs about 3,000 Calories a day. He needs more if he works hard. If he gets less he " burns " the fat which forms part of his actual body. (It is like a railway engine which has run out of coal and has to burn instead the cushions of the seats !) At last the man would starve and die.

FOOD	Calories per pound	FOOD	Calories per pound
Bread (white) .	1,200	Lean meat	600
Potatoes .	400	Fatty fish .	600
Sugar . .	1,800	Eggs . .	650
Butter . .	3,400	Milk . .	370 (per pint)

A calorie, we have learned, makes one gramme of *water* one degree hotter. Suppose we have two tins, one containing water and the other an equal weight of paraffin (kerosene). Let us put the same amount of heat, that is, the same number of calories, into each. We could do this, roughly, by standing each over similar Bunsen burner flames for the same times. Will the rise in temperature be the same in each liquid ? We find that the two liquids do not rise equally in temperature. The paraffin becomes hotter. The heat causes a bigger rise of temperature in the paraffin than in the water. This tells us that *it takes less than one calorie to make one gramme of paraffin one degree hotter.*

By careful measurements scientists have been able to find exactly how much heat is needed to make one gramme of various substances one degree hotter. The table below gives some of the values. Thus 0·5 calorie makes one gramme of paraffin one degree (C.) hotter; 0·09 calorie makes one gramme of copper one degree hotter. We call these values the "specific heats" of the substances. The specific heats have the same values if we use British units. Thus 0·5 *B.Th.U.* makes one *pound* of paraffin one degree *Fahrenheit* hotter.

Substance	Specific heat	Substance	Specific heat
Water .	1	Copper .	0·09
Paraffin .	0·5	Iron . .	0·12
Turpentine (paint oil)	0·45	Lead . .	0·03
Mercury .	0·03	Glass .	0·19
Aluminium	0·2	Earth, rock, sand	0·2

Here is another problem: A block of iron, weighing 10 lb., is to be heated from 50° F. to 200° F. How much heat must be given to it?

The specific heat of iron is 0·12. So—

1 lb. of iron, when heated one degree, needs 0·12 B.Th.U.

But we have 10 lb. of iron; this needs 10 times as much heat. So—

10 lb. of iron, when heated 1 degree, needs 0·12 × 10 B.Th.U.'s.

But we must heat the iron from 50° F. to 200° F., that is, through 150 degrees. This needs 150 times as much heat. So—

10 lb. of iron, when heated through 150 degrees, needs $0 \cdot 12 \times 10 \times 150$ B.Th.U.'s.

The answer is 180 B.Th.U.'s.

You notice that we can get the answer by multiplying together the specific heat, the weight of the substance, and the rise (or fall) in temperature.

Let us now look more carefully at the table of specific heats. We immediately notice that water has the highest specific heat ; all the other values are less than 1. Metals, particularly, have very low specific heats. Suppose we put equal amounts of heat into some water and into an equal weight of a metal. The metal rises far more in temperature. We sometimes say that metals " heat up " more easily. Hold an iron bar in the fire. Its end soon becomes red-hot. The same weight of water, heated on the fire for the same time, might not even boil. Have you noticed that a piece of metal (such as the end of a spade) gets quite hot when left in the sunshine ? The metal heats up quickly. The water in a pool, in the same sunshine, remains fairly cool.

Water heats up slowly. It can take in a lot of heat without becoming very hot. This is one of the reasons why water is chosen to cool the engine of a motor car.

We must remember that when a hot thing is left in the air it cools and gives out the heat which was used in making it hot. A piece of hot metal therefore cools quickly ; the loss of a small number of calories causes a big fall in temperature. Water cools more slowly. It must lose more calories for the same fall in temperature. We sometimes say that water " holds its heat." In cold weather people sometimes put an earthenware bottle of hot water into a bed to make it warm. The water gives out a lot of calories as it gradually cools. A block of iron, of the same weight and at the same temperature, would give out far less heat.

Notice the specific heat of rock and sand. The specific heat of water is about five times as great. One calorie heats 1 gramme of water through 1 degree but heats 1 gramme of rock through 5 degrees. On a hot summer day the ground becomes quite warm but the water in a pool remains fairly cool. At night the ground cools quickly but the water cools slowly. The water may then be warmer than the land.

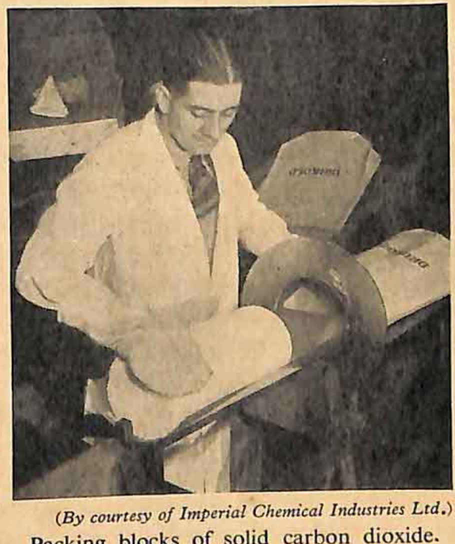
In the same way the temperature of the sea rises slowly, even in the summer, and cools slowly, even in the winter. For this reason, countries near the sea (particularly islands) have a fairly " even " climate ; there is not a great difference between the temperatures at different times of the year. Great Britain is completely surrounded by sea. The climate is therefore never very hot nor very cold. At places in the middle of a big mass of land, such as Moscow in Russia, the summers are fairly hot because the land heats up quickly, but the winters are very cold because the land soon loses its heat.

CHAPTER IX

MELTING AND FREEZING

WATER is a liquid. If we boil some water it changes into steam. We usually call steam a vapour. A vapour is a gas which is not much hotter than the boiling liquid and can easily be changed back into a liquid. If we make some water cold enough it freezes. It turns into the solid which we know as ice. We see, then, that the one kind of material can exist in three forms: a solid (ice), a liquid (water), a gas or vapour (steam).

Many materials can exist in these three forms although



(By courtesy of Imperial Chemical Industries Ltd.)

Packing blocks of solid carbon dioxide. (Carbon dioxide is a gas at ordinary temperatures.)

we do not give separate names (like ice, water, steam) to the three forms. The wax in a candle is usually a solid. When we light the candle the heat of the flame melts some of the wax and it turns into a liquid. The substances in the melted wax then turn into vapours and burn in the flame. Usually we only see a material in one of its forms. This is because, in ordinary life, we do not often meet very high or very low temperatures. We know iron, for example, as a solid. But iron can be melted and, at a still higher temperature, turned into a gas. Air, at ordinary temperatures, is a gas. If we make it cold enough it turns into a liquid and can even be made into a solid. There are some materials, of course, which do not exist in the three forms. These are the substances which are changed in some way by heat. We cannot, for example, melt sugar. When we heat it and try to melt it, we find that it burns instead.

Suppose we put a pot of water on the fire (or heat it over a gas flame). Heat goes into the water ; the heat causes the temperature to rise. After a time the water boils. The liquid (water) begins to turn into a vapour (steam). This happens at a temperature of 100° C. Let us leave the pot on the fire. The water continues to boil. Suppose we take the temperature of the water which has been boiling for some time. We find *it is still 100° C.* The water has a fixed boiling point ; although we continue to put heat into the water the temperature does not rise.

Suppose, in a similar way, we put some small bits of ice in a tin and gently warm the tin over a small flame. The ice begins to melt and form water. If we keep the mixture of ice and water well stirred, the temperature stays the same (0° C.) until all the ice has melted. The ice has a definite melting point ; although we continue to add heat the temperature does not rise until all the ice has melted.

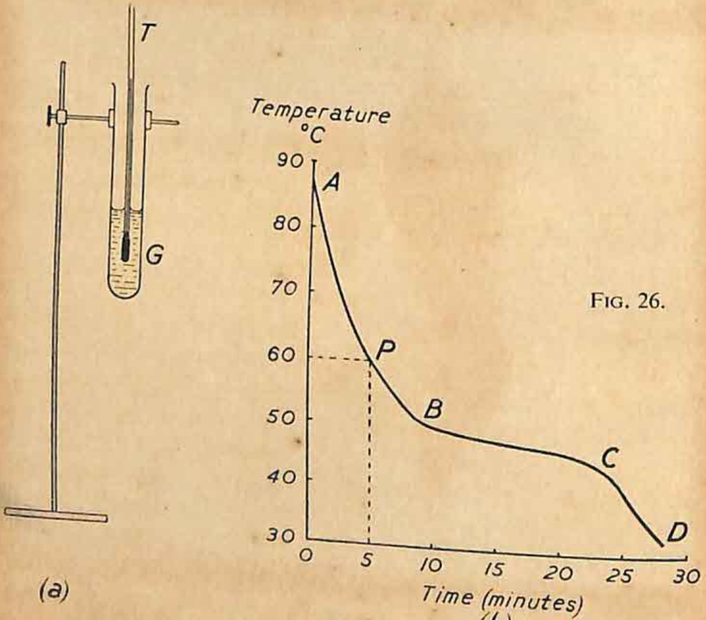
We usually expect that when we add some heat to a thing it becomes hotter. But when ice is melting or water is boiling we add heat and yet the temperature does not rise. The heat must be used in doing something else. In each case a change of form of the substance is taking place. In one case a liquid (water) is changing into vapour (steam) and in the other case a solid (ice) is changing into liquid (water). We learn that heat is used up to produce the change of form. This effect was first studied by Joseph Black (1728–99). He realised that *heat is taken in* when a solid changes into a liquid, and a liquid into a gas, but this heat does not show itself by causing a rise of temperature. He called this heat " latent heat." *Latent* means " hidden," or " carried inside." The heat is hidden

(*Fox Photos Ltd.*)

Glass becomes soft when it is heated. With great skill this man is shaping a glass vessel in a gas flame.

because a thermometer does not show that the substance has received it.

A liquid, then, contains more heat than the solid from which it is made; a gas contains more heat than the liquid from which it is made. We may now ask: What happens to the latent heat when a gas changes back to a liquid again or a liquid freezes to make a solid again? Fig. 26a shows a wide glass tube G containing some candle wax. At first the tube of wax is supported in a tin of water and the water boiled. The wax becomes hot and melts. The tube is then taken out from the water and supported in the air so that it cools. The temperature is taken every half-minute by means of the thermometer T. After a



(a)

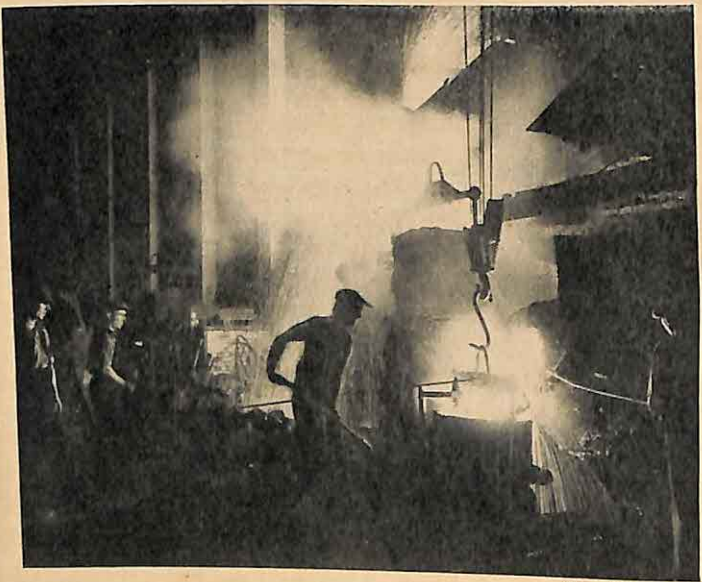
(b)

FIG. 26.

time the wax becomes solid again (and the thermometer becomes stuck in it) but we continue to take the temperatures. Fig. 26 b is a graph. Temperatures are marked upwards and the time sideways. The point P, for example shows that the temperature after 5 minutes was 60° C. We see that the graph consists of three parts. In the first part AB the cooling is fairly quick; during this time the wax is still melted. In the last part CD the cooling is slower (because the wax is less hot); the wax is now solid. In the middle part BC the temperature hardly falls for several minutes. There is no reason to think that during this time the wax stops losing heat to the air around it. When we do the experiment we notice that during this time the melted wax is changing into solid wax. When this change is taking place the wax *gives out* (*or sets free*) *its latent heat*. This extra heat makes up for the heat lost to the air so that, for a time, the temperature does not fall. In a similar way, steam gives out its latent heat when it changes back to water.

A pure substance has a definite, fixed melting point. Thus ice melts at 0° C., lead at 327° C., sulphur at 444° C. Some other melting points are shown in Fig. 22, p. 57. Some metals become soft before they melt. Materials which are mixtures of several similar substances melt gradually over a range of temperatures. Candle wax, for example, melts over a range of degrees near 50° C.; glass softens with heat and gradually changes into a liquid.

By accurate experiments scientists have found that if we have one gramme of ice at 0° C. (that is, ready to melt) we must put in 80 calories to melt it. And this heat does not produce a rise in temperature; the melted ice has a temperature of 0° C. The value in British units is 144 B.Th.U.'s for a pound of ice. You can see that almost as much heat is needed to melt some ice as to raise the water



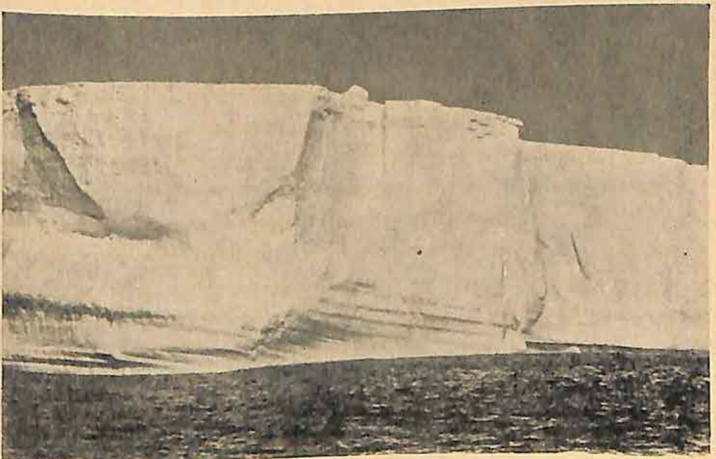
(*Fox Photos Ltd.*)

In a steelworks melted steel is usually carried in buckets hanging from cranes.

which is made from it to the boiling point. Ice therefore melts slowly; a lot of extra heat must be supplied. A layer of snow (which consists of ice crystals) melts slowly even in the sunshine. Icebergs (p. 77) may float thousands of miles into warmer seas before they melt completely. The latent heat of other substances is usually less than that for ice. The latent heat of lead, for example, is about 5½ calories for a gramme. When lead has been raised to its melting point, it melts quickly because only a little extra heat must be supplied.

When water freezes it expands, that is, it increases in size. Very nearly, ten cubic inches of water form eleven cubic inches of ice. Water which has no space in which to expand on freezing produces a very great force. If we fill a bottle with water, put in the cork, and stand it for a time in a freezing mixture (p. 79), we find that the water freezes and drives out the cork. If first we fasten in the cork with wire, the ice breaks the bottle. A very strong force is needed to stop the ice from expanding.

Water-pipes often split when the water in them freezes. The ice may close a narrow part of the pipe. Then the water in the pipe is trapped and has no space in which to expand. When this water freezes it produces a very big force and splits the pipe. People do not notice the split, of course, until after the ice melts again and the water escapes from the pipe. All water-pipes in cold countries (in England, for example, in the winter) should have sacks, cloth, etc., wrapped round them to keep them warm. The freezing of water is one of the ways in which rocks are



(*Fox Photos Ltd.*)

Part of a great iceberg. The part below the water is about ten times as big as the part which can be seen.

broken up, particularly on high mountains where it is cold. Water soaks into cracks in the rocks during the day. When, at night, it is colder, the water freezes, takes up more space, and splits off small pieces of the rock. In the same way " frost " helps to break up the soil.

Ice is slightly less dense than water. We can easily see why this is so. A cubic inch of ice is made from less than a cubic inch of water and so weighs less than a cubic inch of water. Ice floats in water, but, as it is only slightly lighter, only a small part of it shows above the surface of the water. Sailors who travel in cold seas where there are icebergs know this well. The part of the iceberg which is seen above the water is a great mass of ice but the part below the water is about ten times as big. For this reason the sailor does not sail near an iceberg.

Most substances contract when they solidify ; the solid takes up less space than the liquid from which it is made. Melt some wax in a small tin and leave it to cool. The wax near the outside turns into solid first and, because of the contraction, a deep hollow forms in the surface of the wax in the middle. Iron and type-metal (used for making the " type " of the letters when printing a book) are two of the few metals which, like water, expand on solidifying. They can be used for " casting " a metal shape by pouring melted metal into a hollow " mould " and leaving it to become solid. The solid fills the mould completely and takes the proper shape. Good castings cannot be made of metals which contract when they solidify. Like the wax, the solid would have a hollow in the middle and not exactly take the shape of the mould.

We make a solution when we dissolve a solid in a liquid, as, for example, when we dissolve some salt in water. A solution has a lower freezing point than the pure liquid. Sea-water, which contains about 3 per cent. of salt, freezes at − 3° C. Strong solutions have lower freezing points. A very strong solution of salt (23 per cent. of salt) freezes at − 22° C. We shall read later about the large storerooms in ships in which food is kept. The rooms are cooled by cold salt solution which flows in pipes round the walls. The solution is first cooled by a refrigerator (p. 89) to about − 10° C. but it does not freeze. In cold countries the water in the " radiator " of a motor-car may freeze when the engine is not running. Motorists add to the water a substance (often called " anti-freeze ") which consists chiefly of glycerine. The mixture of water and glycerine has a lower freezing point than pure water and, unless the weather is very cold, does not freeze.

Most plants and animals are killed if the liquids inside them freeze. The expansion on freezing breaks the cells of which the plant or animal is made. But the liquids in plants and animals are mostly solutions (of sugar, salt, etc.) and do not freeze so easily as pure water. For this reason a plant or animal can be buried in snow, or even frozen inside a block of ice, and yet not die.

When salt, or any other substance which dissolves in water, is added to ice, some of the ice melts. The ice takes its latent heat from the rest of the mixture and the temperature of the mixture falls to the freezing point of the solution. So, if we throw some salt on snow, the snow melts, but its temperature falls. By mixing some salt with snow or broken bits of ice we can make a mixture which has a temperature of − 20° C. If, instead of salt, we use calcium chloride (4 parts of calcium chloride to 1 of ice) we may make a mixture which has a temperature as low as — 50° C. Such mixtures are called " freezing mixtures." The water in a pot can be frozen by surrounding the pot with a freezing mixture.

CHAPTER X

BOILING AND EVAPORATION

WE have all seen a pot of water boiling on the fire or over a gas flame. Bubbles of steam form inside the water, mostly at the bottom where it is hottest, and rise to the top. The bubbles inside the water make it “jump about” and clouds of steam escape into the air. Boiling, like melting, takes place at a definite temperature. Pure water boils at 100° C. when in the ordinary air (see p. 85), alcohol at 78° C., mercury at 357° C. If the vapour (or gas) is cooled again it turns back into a liquid. We say that the vapour condenses. Actually much of the cloud of steam which we see coming from boiling water consists of very small drops of water. The drops are formed from the vapour which has condensed in the cold air. Steam itself is invisible.

The boiling point of a solution is higher than that of the pure liquid. The vapour, which comes from it, however, is pure; the dissolved substance is left behind. Suppose we wish to make pure water from a solution (e.g. from sea-water). We boil the solution and produce pure water vapour. We then cool the vapour so that it condenses. We call this process “distillation”; we say that we distil the water.

Fig. 27 shows the kind of apparatus which can be used for distilling water. The solution is boiled in the flask F and the vapour passes out through the tube T. The vapour is cooled by the “condenser” C. This consists of a narrow tube inside a wider tube. Cold water from the tap flows in the space between the tubes. The vapour,

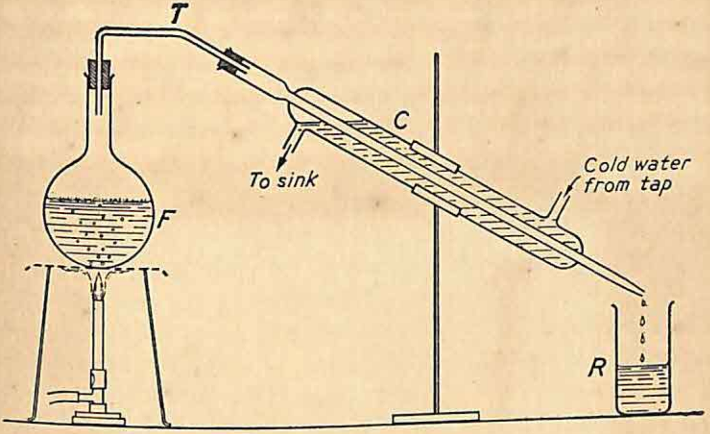
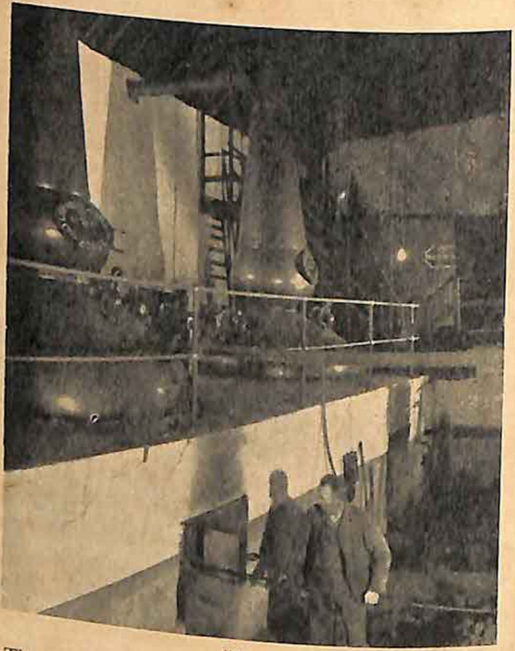


FIG. 27.

which passes down the inside tube, is cooled by the water, and so condenses. The condensed water drips out of the end of the condenser into the container R. A simpler (but less good) apparatus can be without a proper condenser. Instead, the tube T, which must be long, is covered with sheets of wet, cold blotting paper.

Distilled water has no taste and is not pleasant to drink. It is used whenever really pure water is necessary. It is used, for example, when more water must be added to the electric battery of a motor-car.

If we distil a mixture of two liquids, the liquid with the lower boiling point turns into vapour first. This enables us to separate the liquids. Suppose we distil a mixture of water (B.P. 100° C.) and alcohol (B.P. 78° C.). The vapour which comes off first consists largely of alcohol vapour. If we condense this vapour and then distil the liquid again, the vapour which comes off first is almost pure alcohol. Distillation, on a big scale, is an important process. The oil which is obtained from the earth is a mixture of many kinds of oil. The different oils (e.g. petrol, lamp-oil, fuel oil) are separated by distillation. In a similar way, several important substances are separated from coal-tar. In the making of strong drinks (" spirits ") weak solutions of alcohol are distilled to make stronger solutions.



(*By courtesy of Mr. Fenno Jacobs*)

These stills (distilling vessels) for making whisky are like great pots on a coal fire.

We have learned that heat must be supplied to turn a liquid into a vapour. We have called this heat " latent heat." You can make a rough measurement of the latent heat of steam in the following way. Half-fill a small tin with water and take its temperature. We will suppose it is 20° C. Heat the water over a steady flame and find the time taken for it to begin to boil. Suppose this is 2 minutes. Then, using the same flame, find the time taken for all the water to boil away. Suppose this is a further 13 minutes. So, the heat needed to change the water into steam is $6\frac{1}{2}$ times the heat needed to raise the temperature of the water from 20° C. to 100° C., that is, through 80 degrees. But the heat needed to raise the temperature of one gramme of water through 80 degrees is 80 calories. So the heat needed to change one gramme of water into steam is $6\frac{1}{2} \times 80$, that is, rather more than 500 calories. By more accurate measurements it has been found that the latent heat of steam is 537 calories per gramme (966 B.Th.U.'s per lb.). This, as you realise, is a very high value.

When steam condenses it gives out its latent heat. A "scald" on your hand caused by steam is worse than one caused by boiling water. Boiling water gives heat to your hand and so scalds the flesh, but the steam *also* gives its latent heat to your hand, and this is much more.

The most important use of steam is in the steam-engine (p. 127). Great amounts of steam must be made by boiling water. But, because of the high latent heat, it is very expensive to make steam. For every ton of coal which is used in heating the water to its boiling point, several tons are needed to change the water into steam. The boiler of a steam-engine must be carefully arranged so that as much heat as possible goes into the water and very little escapes up the chimney. There are several kinds of boilers. Fig. 28 shows a "water tube" boiler as used, for example, in the engine of a steam-ship. The boiler consists of tubes joined to a container at the top. The water is inside these tubes. The flames and hot gases from the furnace (fire) pass between the tubes. The many

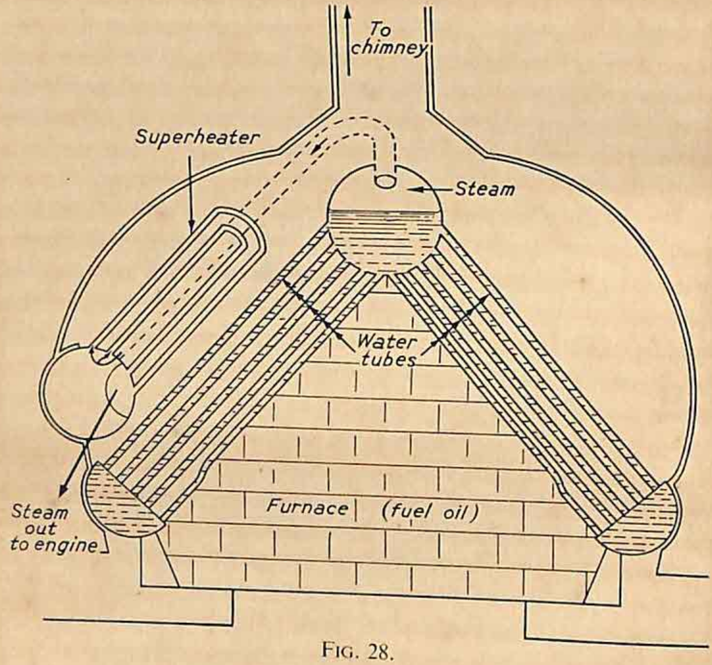
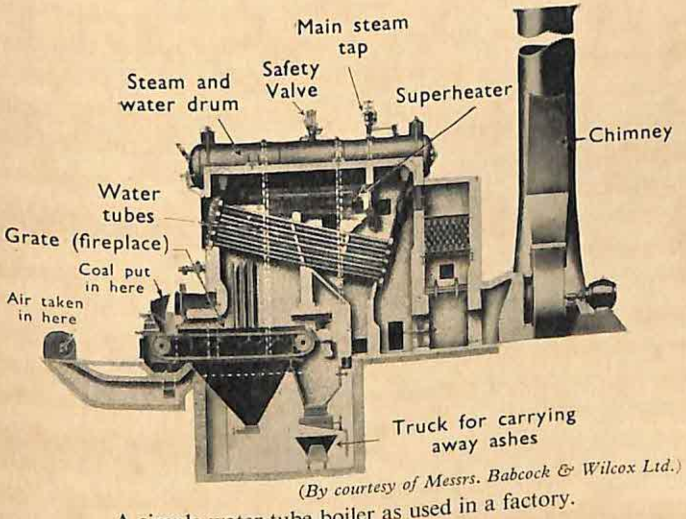


FIG. 28.

tubes have a bigger surface than one big boiler and more heat can get into the water. The steam collects above the water in the container at the top. It then passes through the "superheater." Here it is heated to well above its boiling point (making further use of the heat of the furnace) so that it does not condense before it reaches the working part of the engine. In a railway engine a different arrangement is used. There is one big boiler but the flames and hot gases from the fire pass through tubes inside it.

Steam takes up far more space than the water from which it is made. Very roughly, a cubic inch of water becomes a cubic foot of steam. It is this very great expansion of water when it becomes steam which makes water so suitable for use in an engine. If the steam does not have the space which it needs, it presses very strongly on the sides of its container. (You know how steam presses on the lid of a cooking pot and often lifts it.) Every boiler for making steam must have a "safety valve." This is an arrangement which opens and lets steam out if the pressure becomes dangerously big.

When we say that water boils at 100° C. we mean that it boils at this temperature when it has ordinary air above it. Above the water, or your head, or anything else on the Earth, there is a column of air reaching several hundred miles up into the sky. The weight of this air must be supported by the water (your head, etc.). The pressure is about 15 lb. on a square inch. If you go up a mountain there is slightly less air above you. On the top of Mt. Blanc (15,772 ft.), for example, the air pressure is only



(By courtesy of Messrs. Babcock & Wilcox Ltd.)

A simple water-tube boiler as used in a factory.

just more than half ordinary air pressure. If you heat some water on the top of this mountain you find that it boils at 84° C. The water boils at a lower temperature because, as the air pressure is less, it can turn into steam more easily. On the tops of some mountains you could not make a pot of tea or cook an egg; you could not make the water hot enough. If the pressure above the water is more than ordinary air pressure the boiling point is higher. Suppose we tie down the lid of a pot of boiling water. The steam cannot escape; it collects above the water. The pressure above the water is increased and the water boils less easily. If, for example, the pressure rises to 70 lb. per square inch (instead of 15 lb. per sq. in.) the water boils at 150° C. In a railway engine the pressure may be as high as 300 lb. per square inch, or more, and the boiling point over 200° C.

The pools of water in the road after a shower of rain soon dry up in the sunshine. What has happened to the water? Sometimes, if the sun is shining, you can see "steam" rising from the water. But we would not say that the water is boiling. The temperature of the water is much below 100° C. and bubbles of steam do not form inside the water. The "steam" is formed very calmly at the surface of the water. We call this process "evaporation."

Some liquids evaporate more quickly than others at ordinary temperatures. Put a few drops of petrol, water, and oil (e.g. olive oil) on your hand. The petrol, which has a low boiling point, evaporates quickly; the water evaporates more slowly but dries up after a time, the oil, which has a higher boiling point, does not evaporate enough for you to notice.

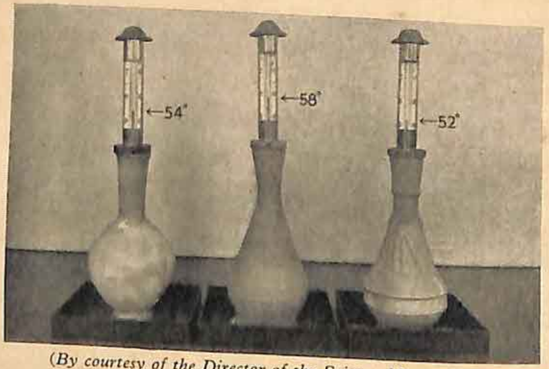
What do you *feel* when the petrol evaporates from your hand? Your hand feels cold where the drops are. When a liquid evaporates there is a change of form: from liquid into vapour. Latent heat must be taken in just as it is taken in when a liquid boils. Yet during evaporation there is no obvious supply of heat such as a fire or a flame. The liquid takes its heat from its surroundings. It takes it from your hand, from its container, from the air around it, or even from the rest of the liquid. Evaporation always causes cooling. When a liquid evaporates it cools itself and its surroundings.

The body depends upon the cooling effect of evaporation to keep its temperature steady. We read in Chapter VIII that we "burn" certain foods in our bodies to give us heat. When we move about quickly or work hard (as in playing football or digging the garden) we burn more food and we feel warm. First, more blood than usual comes near the surface of the body where it can be cooled by the air. Then drops of liquid appear on the body, particularly on the face. We say that we perspire (sweat); drops of perspiration are formed. The drops evaporate and so help to cool the body. In the same way we perspire on a very hot day. We are trying to keep the temperature of the body steady. Men who work in very hot places drink plenty of water, and all of us are more thirsty on hot days. The extra liquid is needed to make up for the loss by perspiration. In a hot, damp climate the perspiration does not evaporate so well. Men who are not used to these conditions do not feel healthy.

By spraying a liquid which evaporates easily on a small area of the body the nerves in that area can be made so cold that a doctor can do a small operation (such as cutting a poisoned swelling) without causing much pain. Children's teeth are sometimes pulled out painlessly by "freezing" the gums in which they are set. A liquid called ethyl chloride is sprayed on the gums. It evaporates quickly and makes the gums so cold that little or no pain is felt.

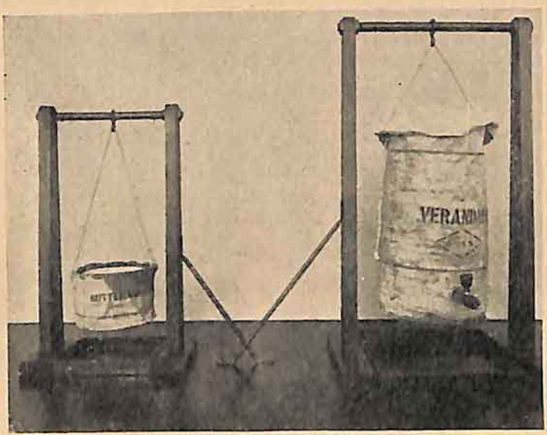
In some hot countries water is kept cool by storing it in big jars made of porous earthenware. (A porous material has many very small holes in it so that it can soak up water. Blotting paper is porous.) Some of the water soaks through the little holes in the jar and evaporates into the air. This keeps the jar and the rest of the water cool. Bottles of water (or beer !) are wrapped in damp cloths and placed in the breeze to cool. Skin water-bottles are used in India for the same reason. The idea is sometimes used in England for keeping butter cool in the summer. The dish of butter is put in an earthenware pot (with a lid) which has been soaked in water. As the water evaporates it cools the pot and the butter inside.

The most important use of the cooling effect of evaporation is in a refrigerator. Refrigerators are machines which "produce cold," or, more correctly, take heat out of things. They are much used for cooling containers in



(*By courtesy of the Director of the Science Museum, South Kensington*)

The cooling effect of evaporation. The three earthenware vessels (from the Sudan) contain water. The middle one is glazed (non-porous) ; the other two are porous. The vessel on the right was stood in a current of air. The temperatures are shown by the thermometers.



(*Photo : Science Museum, South Kensington. By courtesy of Messrs. Anthony Hordern & Sons Ltd., Sydney*)

Canvas water-bag (right) and canvas butter-cooler (left) for use in hot countries.

which food is stored. Cold-storage keeps the food fresh. The germs which cause food to go bad are not active at low temperatures. Below 10° C., for example, the germs which cause milk to go sour do not multiply (increase in number) but above that temperature they multiply quickly. Some foods are carried from one country to another in ships. England receives butter from New Zealand, meat from the Argentine, bananas from the Canary Islands, and so on. There are big cold-storage " rooms " in the ships and these are kept cold by refrigerators. Small refrigerators are sometimes used in houses for keeping food fresh during hot weather.

Fig. 29 is a simple drawing of a small refrigerator as used in a house. The food container is cooled by the evaporation of a liquid. Various liquids are used ; sulphur dioxide and ammonia are two common ones. These substances are vapours (gases) at ordinary temperatures

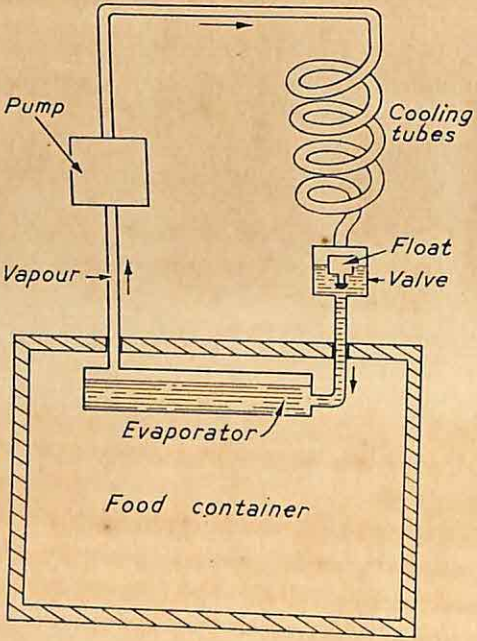
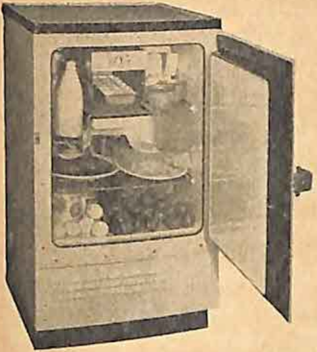


FIG. 29.

but can easily be made into liquids by compressing them. In the drawing, notice the "evaporator" (in which the liquid evaporates) and the pump (driven by an electric motor). The pump first draws in some of the vapour from above the liquid in the evaporator. This causes more of the liquid to evaporate. As it does so it takes in latent heat and cools the inside of the container. Then the pump compresses the vapour which is in it and drives it into the "cooling tubes." Here the vapour loses some of its heat and, being under strong pressure, turns into liquid again. When enough liquid has collected, the float in the valve rises (see the drawing) and lets more



(*By courtesy of the International Refrigerator Co. Ltd.*)

A refrigerator for use in the home.

liquid into the evaporator. This series of changes takes place over and over again.

The cold-storage " rooms " of a ship are cooled by pumping cold brine (salt solution) through pipes along the walls and ceiling (see the picture). The brine is cooled to below 0° C. by refrigerators. On a large ship for carrying food the cold-storage " rooms " have a total volume of over half a million cubic feet.

(*By courtesy of Messrs. J. & E. Hall Ltd.*)

Cold storage " room " in a ship. Notice the pipes in which the cold salt solution flows.

CHAPTER XI

HOW HEAT TRAVELS

(1) CONDUCTION AND CONVECTION

IF we stand near a fire we can feel its heat on our bodies. Heat travels out from the fire. If we put a pot of water on the fire the water becomes hot. Heat travels through the bottom of the pot and spreads through the water. If we pour the hot water into a dish and leave it for awhile it cools. Heat travels from the water into the air around it. If we leave a metal bar (such as a poker) with one end in a fire, the other end gradually becomes hot so that we cannot hold it. Heat travels along the metal bar. In all of these examples heat travels from one place to another. How exactly does heat travel? Does it travel by the same method in all of these examples? The following experiments help us to find the answers.

For the first experiment you need a piece of thick wire about 10 inches long. Dip the wire in melted candle wax (or rub it with a rag soaked in melted wax) so that, when the wax has cooled, the wire has a thin layer of wax all over it. On the top of a block of wood lay a piece of blotting paper and lay the wire on this so that one end stands out about 2 inches beyond the wood (Fig. 30). Now heat this end of the

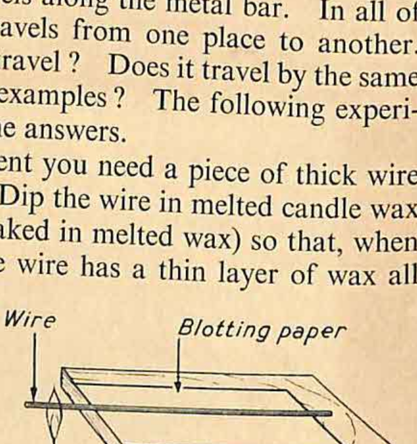


FIG. 30.

wire. You can do the experiment with a candle but a Bunsen burner is better. The wax on the wire near the flame melts. Then the wax a little further from the flame melts; it is soaked up by the blotting paper. Heat gradually travels along the wire and melts the wax.

In this experiment heat is *passed along* the wire. One bit of the wire, near the flame, becomes hot; it passes some heat to the next bit. This bit becomes hot and passes some heat to the next bit, and so on. We call this process "conduction." Heat is "conducted" along the wire from the hot end towards the cold end.

Fig. 31 shows a flask two-thirds full of water. A few grains of dye[1] have been dropped to the bottom. The water is heated by a small Bunsen burner flame. Coloured streams are seen moving upwards and then downwards as shown in the drawing. The heat gradually spreads through the water.

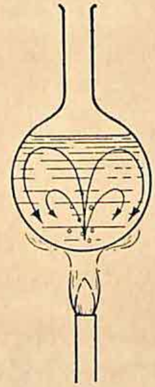


FIG. 31.

We call the moving streams "convection currents." When the water at the bottom is heated, it expands and becomes less dense (lighter). This warm water rises and cold water from the top sinks. This cold water, in turn, becomes warm and rises. So there are streams within the water. The rising streams, being warm, *carry* heat to the top. The heat is carried by convection currents; we say that the heat travels by "convection."

For the next experiment you need a little paper "windmill." You can make it from a circle of stiff paper about 1 in. across. Make eight cuts in it, as shown in Fig. 32 a, and a hole in the middle so that the circle can turn easily

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[1] For example, crystals of potassium permanganate.

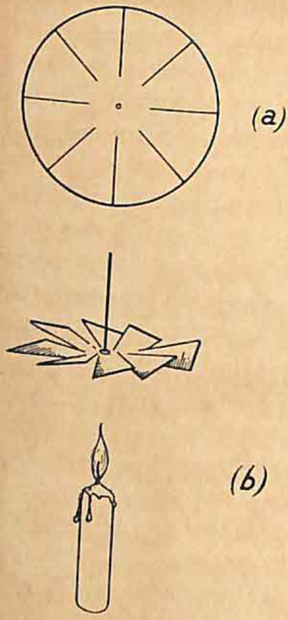

FIG. 32.

on a pin. Twist each of eight parts to make a windmill (see Fig. 32 b). Hold your hand several inches above a candle flame. You can feel the heat. It travels from the flame to your hand. Now hold the windmill above the flame as shown in the drawing. It turns round quickly. There is a stream of air (a convection current) moving up from the flame. Heat travels upwards from the flame by convection.

The heat which reaches us from the sun must travel in yet a different way, for most of the space between the Earth and the sun is empty. (The air reaches for several hundred miles but this is only a small part of the 93 million miles.) There is nothing to pass on the heat or to carry it. The sun *throws* the heat across the space. In the same way a fire throws out some of its heat (but some is also carried away by convection). We call this process "radiation." The sun and the fire radiate heat.

We learn, then, that heat can travel in three ways. It can be passed along (as in a wire), it can be carried by moving streams (as in water and air), and it can be thrown (as from the sun). We have called these three processes conduction, convection, and radiation.

Some materials are much better conductors than others. Metals, particularly silver, copper and aluminium, are very good conductors. Non-metals, such as wood, glass, stone and cork, are poor conductors. Liquids (e.g. water) are poor conductors and gases (e.g. air) are very poor conductors. (Notice, however, that heat can usually travel easily through liquids and gases by *convection*.) If, on a cold day, you touch a piece of metal with your warm hand, it seems cold, but other materials, such as wood, do not seem so cold. Both the metal and the wood are at the same temperature. The metal, being a good conductor, carries heat away from your hand so that it feels cold. Similarly a stone floor seems colder to the bare feet than a woollen mat. The stone is a better conductor than the wool.

You can show that iron (a metal) is a better conductor than wood (a non-metal) by an interesting experiment. You need a block of wood and some iron nails with big, flat heads. Hammer the nails right into the wood so that the heads are level with the surface (Fig. 33). Paste a sheet of thin paper over the wood and the nail-heads and leave it to dry. Now gently move the block about in the small flame of a burner [1] and try to scorch (blacken by burning) the paper. Most of the paper quickly scorches but it remains white (unburnt) where the nails are. The heads of the nails form a white pattern on the blackened paper. The paper scorches above the wood because the wood does not take the heat of the flame away; the paper above the nails does not become hot enough to scorch because the nails take the heat away (down into the middle of the wood).

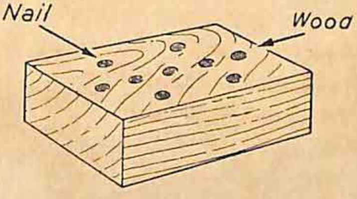

FIG. 33.

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[1] Do not use a yellow flame (e.g. a candle flame) because it will blacken the paper with soot.

Kettles, saucepans, and other cooking pots are usually made of iron or of aluminium. These metals conduct the heat from the fire into the water etc., inside. For the same reason, boilers of steam-engines are usually made of steel. Sometimes copper is used, because it is a very good conductor, but it is not so strong as steel and cannot be used when high-pressure steam is to be made.

An interesting use of the good conducting-power of copper is in the Davy safety lamp which is used in coal mines. In the early days of coal-mining, dangerous explosions were not uncommon. These were caused by a gas called methane (sometimes called " firedamp "). Sir Humphry Davy, an English scientist, found that a mixture of methane and air only explodes if it is raised to a high temperature. He invented an oil-lamp in which the flame was surrounded by a gauze (network) of copper wire. The gauze conducts the heat of the flame away so quickly that the methane outside the lamp does not become hot enough to explode. The idea of this lamp can be shown by an experiment. In Fig. 34 a a piece of copper gauze is held over a Bunsen burner (arranged to give a yellow flame) and the gas lit below it. The gas which passes through the gauze does not light because the gauze takes away the heat. In Fig. 34 b the gas has been lit above the gauze and it remains unlit below the gauze.

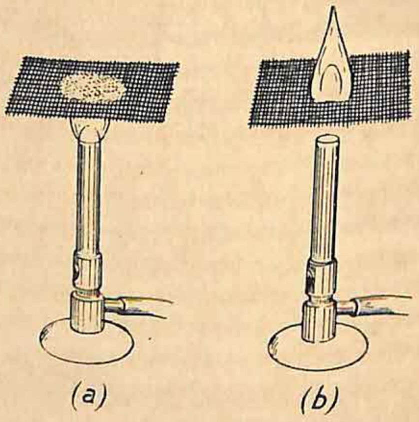
(a) (b)

FIG. 34.

(By permission of the Controller of H.M. Stationery Office, Crown Copyright Reserved)
A miner testing for gas with a safety lamp.

To-day miners often use electric lamps which, of course, have no flames and so are less dangerous. The Davy lamp is still used to test if there is any methane in the mine. If there is methane, the flame inside the lamp burns blue and so warns the miner of the danger.

We often make use of bad conductors in our daily lives. We use wooden handles on cooking spoons, we stand hot plates and dishes on cork mats so that they do not burn the table, we use a piece of cloth or a handkerchief when we pick up something which is hot (such as a pot from the fire). Materials which are such poor conductors that little or no heat can pass through them are called "insulators" (of heat). Many of these materials consist of small particles, or of fibres, with air trapped in the spaces. Air is a very bad *conductor* and cannot take heat away by convection if it cannot move. Loosely woven materials, like cloth, have air trapped in them. In cool countries people wear clothes made from woollen materials. The clothes help to stop the heat of the body from escaping. Linen and cotton materials have less air in them and are not so " warm." Animals' coats help to keep them warm. Fur and wool are very good insulators and hair and feathers are nearly as good.

Notice that an insulator can be used to keep heat *in* or to keep heat *out*. We wrap up a baby in woollen clothes to keep it warm ; we can wrap up a block of ice in cloth to keep it cold. Explorers often use tents and huts which have two " walls " with air between. In cold countries the " double wall " helps to keep the inside of the tent (or hut) warm, and in hot countries it helps to keep the heat out. Refrigerators and cold-storage containers are usually insulated with cork. This insulation keeps the heat out. Pipes which carry steam from one part of a factory to another must be insulated to keep heat in. The insulation is often made of asbestos and magnesia.

Now we must turn to the next way in which heat can travel, that is, by convection. In this process the actual particles of the material move along and carry the heat with them. Such a process cannot take place in a solid because its particles cannot move about, but convection currents are easily set up in a liquid or a gas. Heat is spread through the water in a pot on the fire by convection, and convection currents flow in the air whenever any part of the air is heated.

Hold your hand a few inches above a candle flame. You soon have to take it away because it becomes so hot. The heat is carried upwards by a convection current. You feel much less heat if you hold your hand at the side of the flame. There is always a strong upward current of hot air from a fire. It is this current which carries the smoke upwards. At the same time there is a flow of fresh, cold air towards the fire. Without this supply of fresh air the fire would not burn well. Chimneys help the convection currents to flow. A tall chimney of a factory not only carries away the smoke and fumes ; it also helps to make a strong air-flow so that the fire burns fiercely.

It is interesting to notice that there are some very big convection currents which are not caused by Man. The most important of these are the winds. The Trade winds and the Monsoons, about which you learn in geography lessons, are just big convection currents. The " land and sea breezes," which blow near the coast on fine, fairly calm days, are smaller convection currents.

Fig. 35 a shows a piece of apparatus which can be used for studying convection currents in water. The container C is joined to the flask B by two glass tubes. Notice carefully the ends of these tubes. The left-hand tube starts right at the top of the flask and goes nearly to the top of the container. The right-hand tube, which is bent, starts at the bottom of the container and goes to the bottom of the flask. The apparatus is filled with water to the level of the top of the left-hand tube and then a little dye is put into the water in the container. The water in the flask is heated with a burner. Coloured water, from C, comes down the bent tube and, after it has been heated in the flask, rises up the straight tube. A convection current is set up; it flows in the direction shown by the arrows. If we feel the left-hand tube we find it is quite hot ; hot water goes up this tube. After a time there is hot water in the top container.

This apparatus is really a model of the actual arrangement used for supplying hot water to various rooms in a house. The arrangement is shown simply in Fig. 34 b;

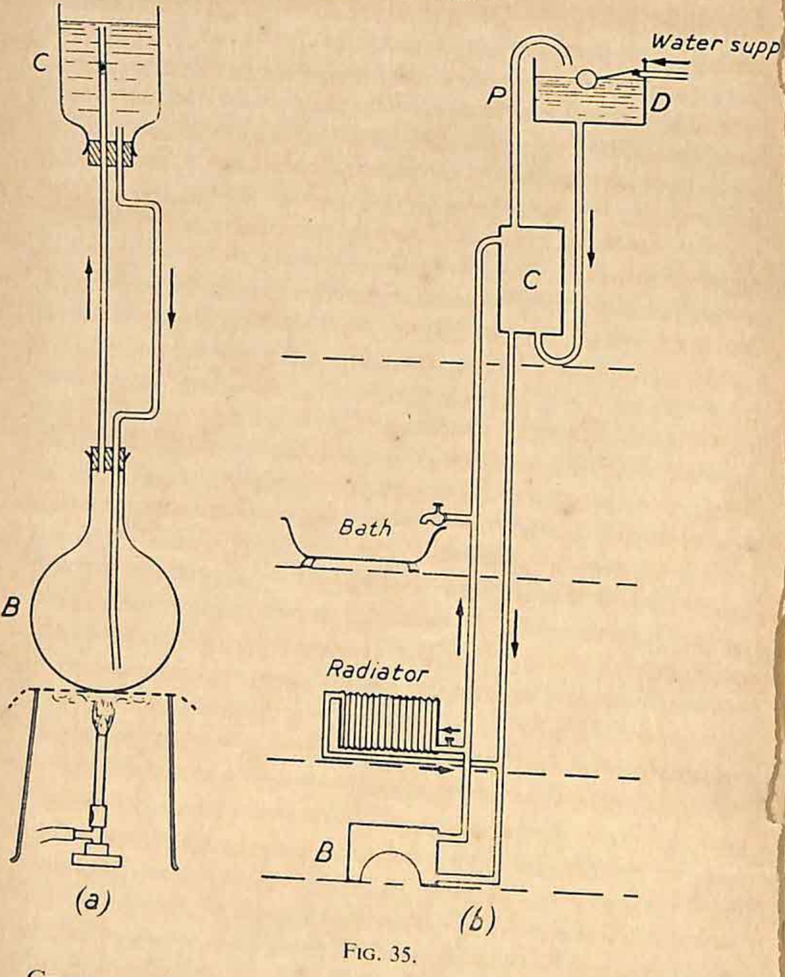

Fig. 35.

Compare this arrangement with the apparatus of the experiment. The boiler B, which is in a bottom room of the house (such as the kitchen), corresponds to the flask. The hot-water " tank " C, which is in an upper room, corresponds to the top container. Hot water goes up the left-hand pipe to the tank and cooler water comes down the right-hand pipe to the boiler. The drawing shows a " radiator " (hot water pipes) for warming a room and a hot-water tap for a bath. As water is taken out when the tap is turned on, and some may be lost as steam, there must be a way of putting more water into the arrangement to keep it full. D is a second tank, higher in the building than C. This tank is kept full of water from the main water supply to the building, and, when necessary, water flows down into C. The open pipe P is a " safety " pipe. It lets out any air which may be set free from the water and also any steam which would be formed if the water boiled. You notice that the water moves round by convection. In very big buildings, however, a pump must be used to help the water along.

The cylinders in a motor-car engine are cooled with water (p. 69). The water flows in special channels round the cylinders and takes away some of the heat. It is cooled in the radiator in the front of the car (Fig. 36). The fan helps to cause a stream of cold air between the many small pipes in the radiator. The water moves round, as shown, by convection.

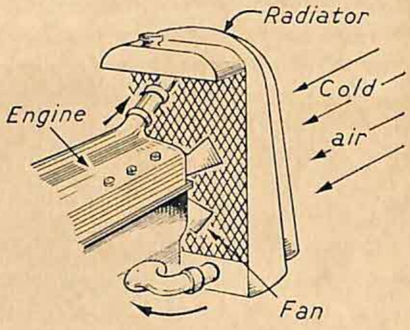

FIG. 36.

In cool countries, such as England, a fire is used in the winter time to keep a house warm. The fire also serves another purpose. It causes convection currents in the air.

Warm air goes up the chimney and fresh, cold air comes in under the doors and through any other holes or cracks. Hence there is always a supply of fresh air to the room. It is not healthy always to breathe the same air. The air becomes dirty and impure. When we cause fresh air to enter a room we say we " ventilate " the room. A building should always be well ventilated. Even if there is no fire, a room can be ventilated by convection currents. The air in the room is warmed by people's bodies, lamps, and so on, and if there are holes by which air can enter and leave, convection currents can flow.

The ventilation of a big building is more difficult. Special openings must be made to let fresh air in and impure air out. These must be arranged so that plenty of fresh air comes in and yet the flow of cold air is not so strong that it is unpleasant for people sitting in the room. Sometimes openings are made behind the radiators (hot-water pipes). Then the air is warmed as it comes in. The warm, impure air rises and escapes through openings made in or near the roof.

CHAPTER XII

HOW HEAT TRAVELS

(2) RADIATION

THE third way in which heat can travel is by radiation. The sun, for example, radiates (or " throws ") heat to the Earth. The heat travels for most of its long journey through empty space. Radiation may seem rather a strange process. We can throw a ball, which is a solid thing, but it is strange to speak of throwing heat, which is not a thing at all. We may even wonder if it is really *heat* which travels. Let us think clearly about what we *know*. The sun certainly sends out " something " which travels to us. But this " something " does not heat the space through which it passes. When it reaches a material through which it cannot pass, such as the ground or your body, it is taken in, or, as we say, absorbed. It then makes the material warm. So we know when heat *arrives*, but we do not know what it is like while it is travelling. In this way, radiation of heat is like radiation of light. We cannot actually see light while it is travelling, but we know when it arrives because it enables us to see the things on which it falls. Both heat and light are forms of energy. We can say that the sun (or a fire, or a candle) radiates energy. Some of this energy is of the kind which makes things hot ; some is of the kind which we call light.

Suppose we have a piece of metal which we can gradually make hotter and hotter. It begins to radiate ; it sends out " radiant energy." At first, while it is still only moderately hot, the radiant energy consists only of heat. If you hold your hand near the metal you can feel the heat, but if you take the metal into a dark room you cannot see it. None of the radiant energy is light. After a time, when the metal has been made hotter, it begins to glow red. We say it is red-hot. (This begins at about 500° C.) Now it is sending out radiant energy of two kinds: heat and red light. At a higher temperature still the light becomes brighter and more nearly white. At about 1000° C. it sends out heat and white light. We say it is white hot.

We see, then, that when a thing is only moderately hot the radiant energy consists only of heat, but above a certain temperature both heat and light are radiated. Very hot things radiate more light than heat. Radiant energy (heat and light) travels at a speed of 186,000 miles a second. (This, as you might guess, is the fastest speed known.) We call a very thin beam of light a "ray." Light rays travel straight. We can also speak of rays of heat. They too travel straight.

You may, perhaps, wish to ask a certain question. If the sun's rays pass through the air without warming it, how is it that the air becomes warm? The radiant energy goes through the air but is absorbed by the ground. The ground becomes warm. The ground heats the air near it and then the heat is spread by convection. We know that this is the correct explanation because the air is warmest near the ground. High up from the ground the air is colder, although, in fact, it is a little nearer the sun there.

Some hot things radiate better than others. The sun, for example, sends out more energy (in each minute) than a fire, and a fire sends out more energy than a dish of warm water. The rate (speed) at which a thing radiates clearly depends upon its temperature. Very hot things radiate more quickly than less hot things. The rate increases very much with rise of temperature. A thing which is just red-hot (500° C.) radiates about 16 times more quickly (that is, 16 times as much energy in a minute) than a thing which is only at a temperature of 100° C.

The rate of radiation, however, also depends, but to a less amount, on *the nature of the surface* of the thing which is radiating, that is, whether the surface is rough, shiny, black, white, and so on. In order to study how the rate of radiation depends upon the kind of surface we must test different kinds of surfaces which are kept at a certain fixed temperature. (If the surfaces are not all at the same temperature we should not know if any difference in the rate of radiation is due to the surface or to the temperature.) Fig. 37 shows a metal box on legs. It can be heated by passing steam through it.[1] Each of its sides is made different. One side is made dull black by covering

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[1] Sometimes the box is heated by boiling water in it but this is not so satisfactory.

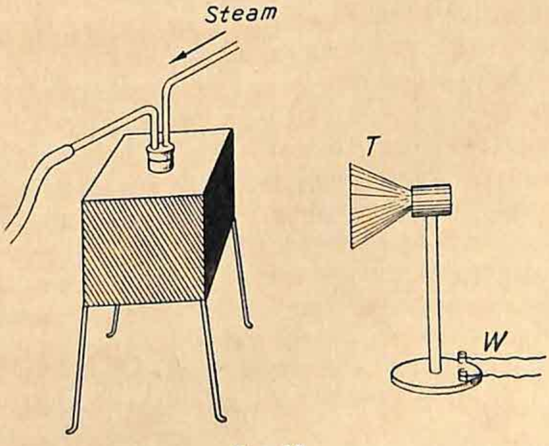

FIG. 37.

it with soot, one is painted with *shiny* black paint, one is painted dull white, and the other metal side is brightly polished. Such a box is called a Leslie cube after the man who invented it. Each side is at the same temperature (100° C.) because each is heated by the steam.

The amount of radiation from the sides of the cube is not great because they are not very hot. We must use a special instrument for measuring the amount of heat which is radiated. The most convenient instrument is called a thermopile. It works by the thermo-electric effect (p. 59). Inside there are strips of two different metals (antimony and bismuth). The heat falls on the joins of the metals and makes a little electric current. The size of the current, which can be measured with a galvanometer, shows the amount of heat which reaches the instrument. In the drawing the thermopile T is standing in front of one side of the cube. The wires W lead to the galvanometer. When doing the experiment, care must be taken that no heat reaches the thermopile from the boiler which makes the steam or from the steam which escapes from the cube.

The thermopile is placed in front of one side of the cube and, after it has warmed up, the size of the current is measured. Then it is stood at the same distance from another side of the cube and the measurement taken. The third and fourth sides are tested in the same way. It is found that the rough, black surface radiates best, the shiny black and dull white surfaces come next, and the polished metal radiates worst. So we learn that black things radiate better than light-coloured things, and rough, dull things better than smooth, shiny things.

If, therefore, we want a thing to radiate well, we should make its surface rough and dark. Hot-water pipes ("radiators") are usually painted a dark colour for this reason, though, in fact, more of the heat is spread by convection than radiation. If we want a thing to lose little heat by radiation we make it bright and shiny. Silver teapots and metal covers for hot food are good examples. For the same reason, kettles and other cooking pots should be kept bright and shiny.

We have learned that the radiant energy sent out by a hot thing travels until it is absorbed. The thing which absorbs the energy becomes warmer. Some kinds of surfaces *absorb* better than others. There are several experiments for testing which kinds of surfaces absorb best.

For the first experiment we need two thermometers which are exactly alike. The bulb of one of them is made black with soot and the other is left shiny. The thermometers are supported in front of a source of heat (a Bunsen burner flame or a small electric heater) but, at first, the bulbs are protected by a wooden screen. The bulbs must be at the same height and at the same distance from the source of heat. The screen is taken away and the temperatures, as shown by each of the thermometers, read every half-minute. It is found that the temperature as shown by the thermometer with the black bulb rises more quickly. Each thermometer *received* the same amount of heat but the black surface *absorbed* the heat better.

For the next experiment you need a substance called cobalt chloride. You can probably get some at a chemist's shop. Cobalt chloride usually consists of pale red crystals and when it is dissolved in water it makes a pale red liquid. Dip a match-stick into this liquid and " write " on a piece of paper. When the writing dries you can hardly see it. Now hold the paper in front of the fire. Very soon the writing shows clearly—it is bright blue. When cobalt chloride is heated so that it thoroughly dries, it changes from pale red to blue.

To test which kinds of surfaces absorb heat well you need a sheet of thick, soft paper about 1 foot square. It is soaked in cobalt chloride solution and left to dry. A circle about 3 in. across is drawn in the middle. This is painted with aluminium paint (or, if you like, you can paste on a piece of "silver" paper). This circle is therefore shiny. Draw another circle round this so making a ring about an inch wide. This ring is painted black. There are now three different parts of the paper: the shiny middle A, the black ring B, and the outside part C (Fig. 38). It is convenient to fix the paper to a wooden frame to keep it flat.

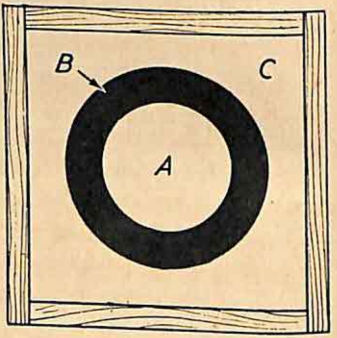

FIG. 38

The paper is held with its painted side facing a source of heat such as a fire or a small electric heater. All parts of the paper *receive* heat equally from the source. Do they *absorb* the heat equally? Look at the back (unpainted side) of the paper. At first it is pale red. After a short time part of it turns bright blue; it is the part behind the black ring B. The black ring absorbs heat best. The rest of the paper C slowly turns blue but not such a bright blue. This part only absorbs heat fairly well. The middle part A, behind the bright circle, does not change colour; little or no heat is absorbed.

These experiments show that black surfaces absorb heat best, light-coloured surfaces do not absorb well, and bright, shiny surfaces hardly absorb heat at all. People in hot countries often wear white or light-coloured clothes. White clothes absorb less heat from the sun than dark clothes. Snow melts very slowly even in the sunshine. This is partly because the white snow absorbs so little heat.

You will have noticed, of course, that a black surface radiates well (when it is hot) and absorbs well when radiant energy comes to it. Shiny metal surfaces radiate poorly and absorb poorly. Get a piece of white cardboard on which there is some black printing (a piece of a cigarette packet will do). The dark printing absorbs heat and light; that is why it seems dark. The white part does not absorb well. Throw the cardboard on to the fire. After the flame has died down, the ash often remains whole (unless you disturb it). This ash glows with the heat. But the part which glows most brightly is where the printing was, in fact, you can sometimes read the printing. The printing absorbed better than the white card; now the printing is radiating better than the other part.

We may ask what happens to the radiant energy which hits a substance but is not absorbed. Some may go through the substance. Heat, like light, passes through air. Most materials which let light through also let heat through. Glass, strangely, lets light through but does not let heat through. You can use a piece of glass as a screen in front of a fire. But, you may say, we sometimes put glass over growing plants to make them warm and grow some plants in glass greenhouses. We must remember that plants are warmed by *sunshine*. The radiant energy from the sun consists largely of light because the sun is so hot. The light passes through the glass. It is absorbed by the plants, soil, etc., inside and makes them warm. The warm plants and soil then radiate a little heat. This heat cannot get out through the glass. The heat, therefore, is trapped inside the glass.

More usually the heat which is not absorbed is reflected, just as a mirror reflects light. A piece of brightly polished metal reflects heat very well. A piece of curved metal is often put behind the heater of an electric " fire " to reflect the heat forwards.

In our study of the ways in which heat travels we have described each way separately. We must not think that heat travels from a hot thing in one of these ways only. It is true that the heat from the sun travels only by radiation, and that most of the heat of a candle flame is carried upwards by convection, but more often heat leaves a thing in two or more ways at once. Suppose we have a cup of hot tea on a silver tray. It gradually loses heat. A little of the heat is *conducted* through the bottom of the cup and conducted away by the tray, some is conducted through the sides of the cup and carried away by *convection currents* in the air, some is carried away by convection at the top, a little may be *radiated* (but not much because the tea is not very hot), and some may be lost by *evaporation* at the top surface of the tea (p. 87). So the heat travels from the tea in several ways at once.

Now suppose we want to keep some tea hot. How can we stop heat from escaping in each of these ways? The most serious loss of heat is by convection. We can stop this loss of heat if we take away the air from near the cup. This is the chief idea in a " vacuum flask "[1] (Fig. 39).

The main part of the flask consists of two glass vessels one inside the other. The air is pumped out from between these vessels so that the space is quite empty. The space is a " vacuum." (In the drawing you can see the tube through which the air was pumped out; after the

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[1] Often called a Thermos flask after the name of a well-known make.

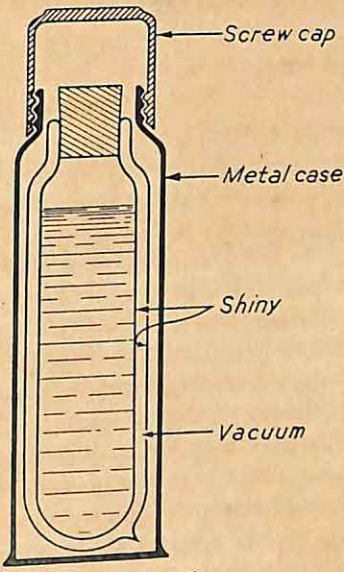

FIG. 39.

pumping it was closed up.) The glass vessels are protected by a metal cover. The tea is put inside the inner vessel and a cork put in the top. Very little heat can leave the tea by conduction because the inner vessel only touches the rest of the flask at the top. No heat can be carried from the sides by convection because there is no air there and the cork stops a current of air from rising at the top. The cork also stops evaporation. Very little heat is lost by radiation. Even this can be made less by painting the outside of the inner vessel with metal paint (so that it cannot radiate well) and also the inside of the outer vessel so that it reflects back any heat which is radiated. The tea in the flask keeps quite hot for several hours.

A vacuum flask also keeps cold things cold. (It does not make cold things hot as foolish people sometimes suppose !) You can think out for yourself why heat cannot easily get *into* the flask. The vacuum flask was actually invented (by Dewar in 1892) for the storing of liquid air.

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CHAPTER XIII

FIRE IN THE SERVICE OF MAN

(1) HEAT

FIRE, we have said, is one of Man's greatest discoveries. It is difficult to realise how much we owe to fire. Without it our way of living would be completely different; we should be like the early Man who lived on the Earth tens of thousands of years ago. We use fire in two ways. We use it as a source of heat and we use it as a source of power (e.g. in an engine). In this chapter and the next one we shall try to examine some of the more important uses which Man has made of fire.

In the home, of course, we use a fire to keep us warm in cold weather, and, in various ways, for cooking our food. These two uses—warming and cooking—were among the first uses which Man made of fire. For hundreds of years the same fire was used for both purposes. Now we more often use a separate fire for each purpose. Each fire can be built so that it is particularly suitable for its purpose. The fire-place in a modern English home, for example, is built so that as much heat as possible is sent into the room. Cooking is still done over an open fire in some parts of the world but more often specially made ovens are used. Some ovens are heated by burning wood or coal. In England, gas-ovens (heated by burning coal-gas) are more common and ovens heated by electricity are gradually becoming popular.

Fire, too, has been an important source of light in the home. In very early times, the fire itself was the only source of light which Man could make. Gradually he found out how to make lamps and torches which depended upon the burning of plant-oils and animal-fats. At a much later date the candle and paraffin oil (kerosene) lamp were invented. In some countries gas-lamps have been used, and still are fairly common. The modern source of light, of course, is the electric lamp. This does not depend upon fire but upon heat which is produced electrically. The electric generator, however, may be driven by a steam-engine and that depends upon fire.

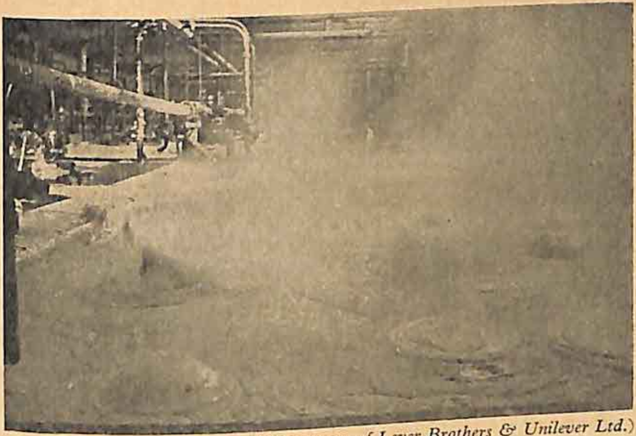
We often use a fire when we wish to destroy things. We burn old paper, rags, dead plants, and other rubbish. Fire also destroys living things. You may be able to hold your hand in a flame for a little while before it actually burns (though it would be painful !) but, in time, the flesh would be destroyed. The destroying of living things by fire is important in one special way : we can destroy the germs which cause disease. A hundred years ago, nearly half the people died after a doctor's operation such as cutting off a leg. Disease germs, from the doctor's instruments, bandages, etc., entered the wounds. Now all the knives, instruments, bandages, and other things which the doctor uses are passed through a flame or heated in steam before they are used. The germs are killed. It is very rare now for a person to die because germs enter the wounds in an operation. This process of killing germs is called "sterilisation." By this simple process thousands of lives are saved every year. For a similar reason, the burning of bodies after people have died, which is common in some countries, helps to prevent the spread of disease.

Diseases can also be spread by unclean milk. Germs live well in milk and quickly multiply because it is such a good food. Even a few germs can multiply so quickly that after a few hours the milk is dangerous. Great care must be taken to keep milk clean. The sheds in which the cows live must be clean; the cows should be milked by machines (not by human hands); the milk should be put into sterilised bottles (or other containers). The milk itself is "pasteurised." It is heated to about 145° F. (65° C.) for half an hour. This kills most of the active germs which might be in the milk. After the milk has been pasteurised care must be taken, of course, not to let new germs enter it again.

In different parts of the world many different kinds of material have been used for building houses. The most common material is brick. Bricks are made by baking

(*Fox Photos Ltd.*)

Brick-making.



(By courtesy of Lever Brothers & Unilever Ltd.)

Soap making. Oils and fats are boiled with caustic soda.

clay. In very hot countries bricks can be made by heating clay in the sun but the best bricks are made by heating in a special oven. The clay is ground to a fine powder and mixed with a little water (and sometimes some sand). It is then soft and sticky. It can be pressed into the proper shape. After drying in the air, the bricks are baked in the oven to make them hard. We sometimes say that the bricks are "fired"; it reminds us that fire is very important in brick-making. A builder joins the bricks together with "mortar." He makes a paste of lime, sand, and water, and puts it, while it is still soft, between the bricks. It gradually becomes hard and joins the bricks together. And from where do we get lime? It is made by *heating* limestone. Cement is another important building material. It is made by *heating* a mixture of finely ground clay and chalk.

Most buildings have glass windows. Ordinary glass is made by heating a mixture of sand, soda, and lime. The mixture melts to form a clear, sticky liquid. When it cools it forms solid glass. A very hot furnace (1500° C.) is needed for glass-making. It is usually heated by burning a gas. Heat is also needed in nearly every step of "working" glass, that is, shaping it into sheets, tubes, containers, and so on.

Inside the house we find that many different materials are used for making the various things which we use. Cups, plates, and pots are usually made of earthenware or china. They are made in a similar way to bricks, that is, by baking shaped clay. In recent years great use has been made of "plastics." Trays, ornaments, electric-light fittings, door handles, and even furniture are a few of the many things made from this new kind of material. Plastics are artificial (man-made) substances something like hard gum or resin. At some step in their making they are soft and can be shaped by heat and pressure. Afterwards they become hard. Heat is very necessary in the making of these materials. Rubber is another

(*By courtesy of the Dunlop Rubber Co. Ltd.*)

Machine used for "moulding" rubber tyres.

useful material. The rubber as obtained from the tree is soft. By means of heat and treatment with certain chemicals, it is changed into a tough material which can be shaped and which wears well. The process is called "vulcanisation." As only a moderate temperature (150° C.) is needed the rubber is heated by hot steam.

Metals are very important materials. A look round your home will show you the many ways in which metals are used. Knives, tins, tools, wire (for electric lamps), ovens, nails, buckets are some of the obvious metal things. Outside the house we think of motor-cars, trains, aeroplanes, bridges, and machines. Fire, as we shall see, plays a big part in the making, shaping, and joining of metals.

Not many metals are found "free" (that is, as pure metals) in the ground. Most are found in the form of "ores." The ore is a rock containing a *compound* of the metal. A compound, we know, is made when two (or more) elements join together. Many ores consist chiefly of the oxide of the metal, that is, the metal is joined with oxygen. (In some ores, e.g. zinc ore, the metal is joined with sulphur.) The oxide, of course, looks quite different from the shiny metal which it contains. Man has found out how to get the metals from the ores, or, as we sometimes say, how "to win" the metal from the ore, and, in nearly every case, he uses fire. As we cannot describe the process for each of the metals,[1] we will read about the making of the commonest and most widely used metal. That metal is iron.

Iron ore consists chiefly of iron oxide mixed with other useless rock. The problem is to separate the iron from the oxygen to which it is joined. We know that carbon joins very strongly with oxygen. It does this, for example, when coal burns on a fire. If we heat a mixture of iron oxide and carbon, the carbon joins with the oxygen in the oxide and so sets the iron free. We can write the process so :

---

[1] The processes are described in *Treasures from the Earth* in this series.

iron oxide + carbon —> iron + oxides of carbon.

We can use almost any form of carbon—charcoal, coal, coke. The oxides of carbon (there are two kinds) are gases ; they escape and leave the iron behind.

Four materials are used in the making of iron. We already know two of them : iron ore and carbon. Coke (p. 23) is the best form of carbon for this purpose. Then we must have air so that some of the carbon can burn and provide the necessary heat. We also need limestone ; we shall see the use of this later. Fig. 40 is a simple drawing of the kind of furnace which is used. It is about

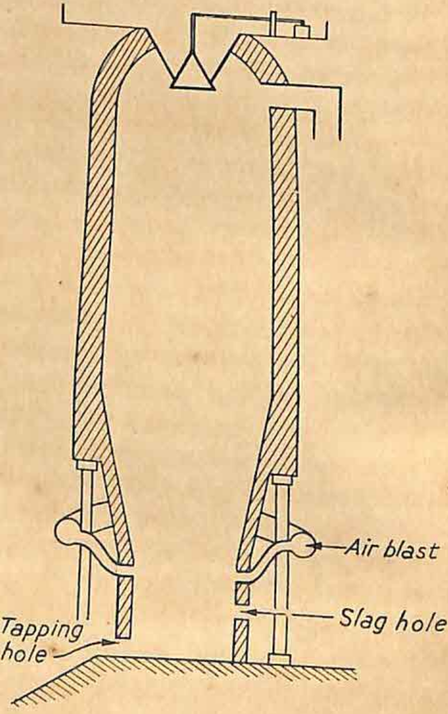


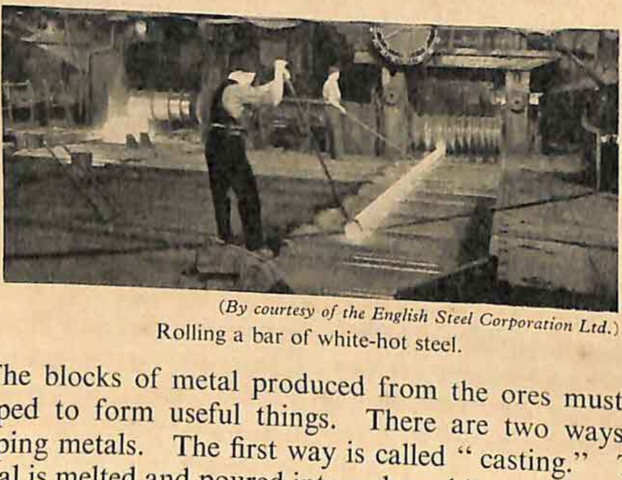
FIG. 40.

100 feet high and 25–28 feet across at the widest part. It is called a " blast furnace " because a blast (strong stream) of air is sent through it. The mixture of ore, coke and limestone is not heated by a separate fire; it *forms* the fire. It is put in at the top. The air blast is sent through pipes near the bottom. Once the fire has been lit, it is kept burning by adding more of the mixture at the top, and may be used, night and day, for two or three years before it is allowed to go out! As the mixture gradually sinks towards the bottom it becomes hotter and hotter. The temperature near the bottom is over 1000° C. The iron is set free but, at that high temperature, it melts. The melted iron runs to the bottom of the furnace. Several times a day a hole at the bottom (called the " tapping hole ") is opened. The melted iron runs out into channels made in a layer of sand. When it cools it forms solid bars.

Part of the iron ore consists of useless rock. In the furnace this rock joins with the limestone and forms a material *which melts*. This material is called " slag." The melted slag is lighter than melted iron and so floats on the iron just as oil floats on water. It runs out of another hole a little higher than the tapping hole.

The iron from the blast furnace is not pure. An iron bar weighing 100 lb. contains about 4 lb. of other substances. These impurities make the iron brittle; it breaks rather easily if it is hit with a hammer or dropped heavily on the ground. Further, it does not become soft when it is made hot, so it cannot be shaped by hammering or pressing. It can, however, be shaped by casting (p. 120). For this reason we call it " cast-iron." Many useful things, such as water pipes, lamp-posts, garden railings, parts of ovens, and certain kinds of cooking pots, are made of cast-iron.

Much iron is made into steel. Steel is a mixture of pure iron and a small amount of carbon. Sometimes small amounts of other metals are also added. To make steel from cast iron, the impurities must be taken away and the carbon added. There are several ways of doing this; all depend upon high-temperature furnaces. The iron is melted and made very hot. The impurities burn away or join with the inside of the container. Then exactly the right amount of carbon is put in.



(*By courtesy of the English Steel Corporation Ltd.*)

Rolling a bar of white-hot steel.

The blocks of metal produced from the ores must be shaped to form useful things. There are two ways of shaping metals. The first way is called "casting." The metal is melted and poured into a shaped "mould" made of a substance (such as firm sand) which does not burn. When the metal cools and turns back into a solid it takes the shape of the mould. This method is particularly useful for making things of complicated shapes. The other way of shaping metal is by hammering, pressing, rolling, and pulling. By means of strong machines a metal block can be pressed into a flat sheet, pulled out to make wire, hammered into the shape of an axle, and so on. Very often the metal is first made hot because then it is softer.

Things made in such ways are usually stronger than things made by casting. Notice the important part played by fire in the shaping of metals. In casting, the metal is first melted ; metals which are shaped by hammering etc. are usually made hot first. And even when cold metals are shaped the machines are driven by engines which depend upon heat.

Heat is also used to change the quality of a metal, that is, to make it harder, stronger, softer, more springy, and so on. Take a steel knitting needle and bend it slightly to feel how tough and springy it is. Now hold it in a flame and, when it is bright red-hot, dip the end as quickly as possible into some cold water. When the needle is cold, try to bend its end. You find that the metal is hard but brittle ; the end breaks off. The " heat treatment " has changed the quality of the steel. By heating to different temperatures and cooling at different speeds, various qualities can be produced. Heat treatment of metals is an important process. Steel cutting-tools, for example, must be treated so that they remain sharp after use.

In the making of many things, from a kettle to a battleship, metals must be joined. Some metal parts, of course, are joined by nuts and bolts. We have already read how metal sheets can be joined by rivets. Many ways of joining, however, depend upon the use of melted metal. We will examine some of these ways.

The best known use of melted metal for joining is the process called " soldering." Solder is an alloy, usually made of lead and tin, which melts at a low temperature (200–250° C.). The ends of the metal parts which are to be joined are cleaned and then held together. A little melted solder is run into the space between them. The solder cools, becomes solid, and joins the parts together. Soldering is used for joining wires in radio sets, mending cracks in lead pipes, joining the sides of tin cans, and in making certain parts of motor-cars. The steel tubes in a bicycle frame are joined by a similar process in which a kind of brass is used as the solder.

Another way of joining metals is called "welding." The melted metal used for making the join is the same kind as that of the parts to be joined. For small joins no extra metal is needed. The ends of metal parts are melted, often electrically, and then pressed together. When the metal becomes solid again the parts are joined. Fig. 41 shows how "spot-welding" is done. This method is particularly useful for joining metal sheets. The sheets are held together and the rods RR, which are joined to an electric supply, lightly pressed on each side. The current flows from one rod, through the sheets, to the other rod. The electric resistance is high between the sheets because they do not touch tightly. Much heat is made there. The sheets are then pressed together. In this way a join is made at the one spot which was heated. A row of such joins can be made very quickly. Parts of motor-cars and aeroplanes are spot-welded; a car may contain over a thousand such joins and an aeroplane even more.

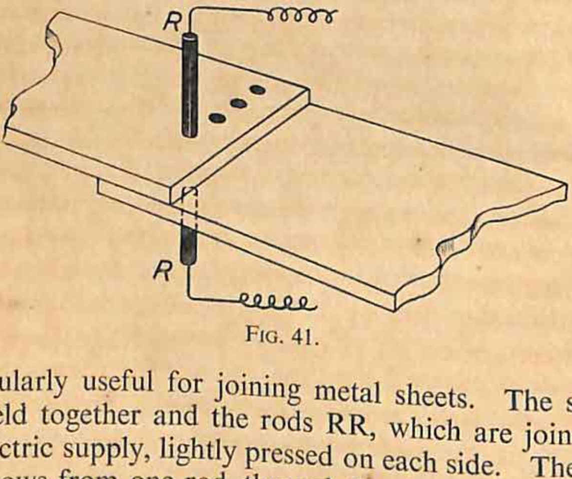


FIG. 41.

For larger joins between two pieces of metal, a third piece (of the same, or a similar kind) is melted into the join. The three pieces are really melted together. They flow into each other and become one. A welded join of this kind is very strong. The high temperatures which are needed to melt the metal are produced by an oxy-acetylene flame (p. 19) or by an electric arc (p. 29).

(By courtesy of the Lincoln Electric Co. Ltd.)

Welding by means of an electric arc.

In this chapter we have been able only to describe a few of the many uses which Man makes of fire. Yet you can see that we depend upon fire for nearly all the things which make our life as it is.

CHAPTER XIV

FIRE IN THE SERVICE OF MAN

(2) POWER

IN early times, as now, Man had to work in order to live. He had to grind his corn, lift water from a well or river, cut down trees, carry materials and supplies. To do such work he [illegible] his own power or that of animals. We still [illegible] own power, when, for example, we dig a field, carry a parcel, and ride a bicycle. But Man's wish for ease, comfort, and convenience grew. He wanted bigger houses, better tools, quicker ways of travelling, and so on. To obtain these, the power of men and animals was not enough. The force which a man or an animal can make is rather small. A man, for example, cannot pull a train. Gradually engines of various kinds were invented. We now use a steam-engine to pull a train and a petrol-engine to drive a car. Such engines can provide very strong forces, can work quickly, and do not become tired. Man now uses engines for doing much of his work.

Engines cannot make something out of nothing. They depend upon natural sources of power. A windmill depends upon the power of the wind; a water-wheel depends upon the power of the waterfall. Most engines depend upon heat. The steam-engine depends upon the heat from the coal which burns below the boilers; the motor-car engine depends upon the heat from the very quick burning of petrol. Engines which depend upon heat are properly called " heat-engines " but, as they are so common and important, we often use the word

" engine " only to mean an engine of this kind. We can say that a heat-engine depends upon fire; by means of the engine the fire does useful work for us.

We learned in Chapter IV that a common (but not very useful) way in which heat is produced is by friction. We use a force to overcome the friction when we make one rough thing slide on another. In science we say that we do some " work " when a force overcomes a resistance and so moves the thing on which it acts. We do some work when we slide one thing over another and, in such cases, heat is produced.

The amount of heat which is produced depends upon the amount of work which we do. How can we measure an amount of work ? Suppose you lift a parcel from the ground. You provide a force (with your arms) to overcome the force of gravity, that is, the pull of the earth which gives the parcel its weight. You do some work when you lift the parcel, although, in this case, the work does not produce heat. If the parcel weighs 1 lb. you must provide a force of 1 lb. to lift it. Suppose you lift the parcel up through 1 foot. *We say that you do one foot-pound of work* (often written 1 ft.-lb.). If you lift a parcel weighing 10 lb. through 5 feet you do 5 × 10, that is 50 ft.-lb. of work. Similarly if you push with a force of 8 lb. to make a rough thing slide 6 ft. over another you do 48 ft.-lb. of work, and so on.

By careful measurements scientists have been able to find out how much work must be done to produce one British Thermal Unit of heat. (We learned about heat units in Chapter VIII.) They have found that 778 ft.-lb. of work produce one B.Th.U. of heat.

In this chapter we are interested in the opposite change. How can we make heat do useful work for us ? How can we use heat to turn wheels, drive machines, and so on ?

Let us suppose that, by the use of some kind of engine, we can change all the heat given out by a burning candle into useful work. How much work could be done? An ordinary wax candle weighs about $\frac{1}{8}$ lb. (or perhaps rather more); the heating power (p. 65) of wax is about 16,000 B.Th.U.'s per pound. So one candle, weighing $\frac{1}{8}$ lb., produces about 2,000 B.Th.U.'s if it completely burns away. Now we have said that 1 B.Th.U. is equal in value to 778 ft.-lb. So the heat from the candle is equal in value to 2,000 × 778, that is, 1,556,000 ft.-lb. Let us try to think what this amount of work means. You will find, if you make the calculation, that this is the amount of work which is done in lifting a weight of 10 tons through 70 feet. Perhaps you are surprised that the heat from one small candle can do so much work. But we must remember that we can only get this much work if we can invent an engine which will change the heat into work and if the engine changes *all* the heat into work. Here we meet two very important problems: how to make a heat-engine and how to make it change as much heat as possible into useful work. We cannot, in this book, describe all the kinds of heat-engines in detail but we shall try to look at the chief ideas on which they depend.[1]

The well-known steam-engine, as used for pulling trains, was not invented by any one man. It gradually developed as the result of the skill of several engineers. The man who made most inventions and improvements was James Watt. At first, the steam-engine was used for pumping water from mines. It was soon after 1800 that the first railway was made. Now almost every country in the world has railways, and thousands of machines, in many factories, are driven by the power of steam.

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[1] You can read more about engines in *Machines and Engines* in this series.

Let us see the chief ideas on which a steam-engine depends. Look at Fig. 42. On the left you can see the piston and the cylinder. The cylinder is a strong, wide tube closed at its ends. The piston is a block, on the end of a rod, which fits inside the cylinder. It fits so tightly that steam cannot get past it but it can slide backwards and forwards in the cylinder. The drawing shows two pipes P_1 and P_2, one at each end of the cylinder. (We shall see later what these are really like.) Suppose steam is passed from the boiler into the cylinder through P_1. It presses on the piston and pushes it towards the right. Next suppose that, after the piston has moved to the right-hand end of the cylinder, we stop the supply of steam through P_1 but pass some fresh steam into the cylinder through P_2. This steam pushes the piston back to the left-hand end of the cylinder, driving out the "used" steam through P_1. Then we can pass the steam in through P_1 again, and so on, and in this way make the piston move backwards and forwards.

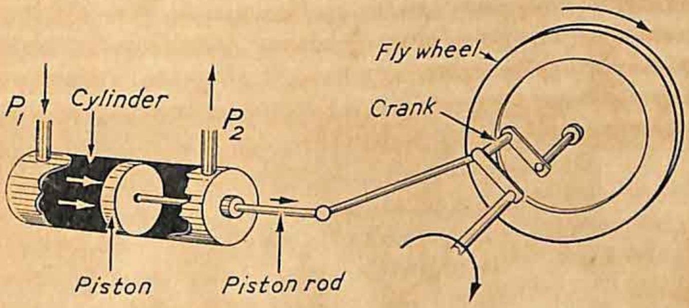
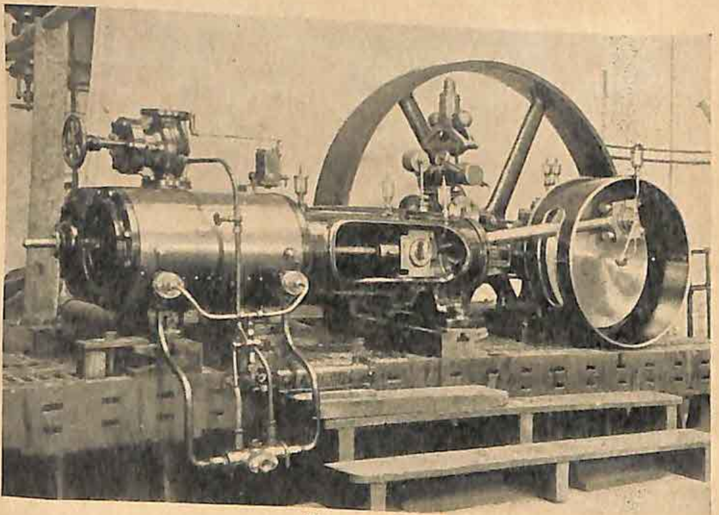


FIG. 42.

A backwards-and-forwards movement is suitable for some purposes, such as working a pump, but more often we want an engine to turn wheels. We must change the backwards-and-forwards movement into a round-and-round movement. We have a similar problem in a bicycle. We push *downwards* on the pedals ; we want the wheels to *turn*. Fig. 42 shows how a " crank " is used to change the backwards-and-forwards movement of the piston into a round-and-round movement. The crank turns an axle on which there is a heavy wheel (called a fly-wheel). This wheel helps to keep the turning-movement steady. Machines can be driven by this or other wheels on the axle.



(*By courtesy of Messrs. Marshall Sons & Co. Ltd.*)
A small single-cylinder steam-engine. You can clearly see the piston rod, crank and fly-wheel.

We must now see, in more detail, how the steam is made to pass into the cylinder, first to one side of the piston and then to the other. The simplest way is by means of a " slide-valve." This is shown in Fig. 43. You can see

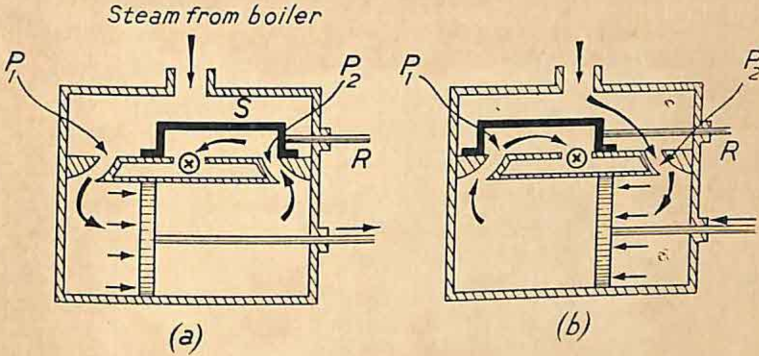
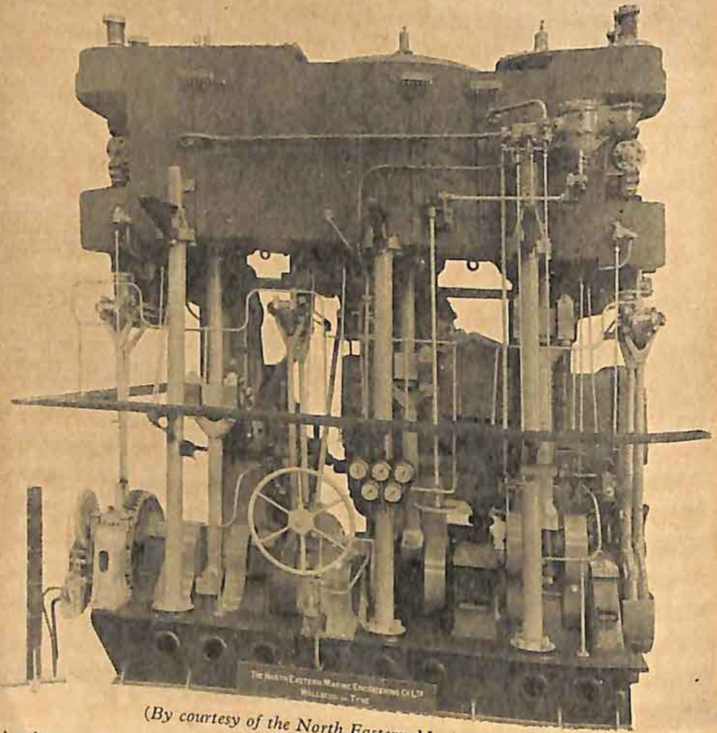


FIG. 43.

the piston and cylinder, in the lower half of each drawing, and the pipes P_1 and P_2. The slide-valve S is shown in black. It is pushed backwards and forwards by the rod R. X is the beginning of the outlet through which " used " steam escapes. In (a) the slide-valve is towards the right. Steam, which comes in at the top, can pass through P_1 to the left-hand side of the piston. The steam cannot get in through P_2, but the " used " steam to the right of the piston can escape into X. In (b) the slide-valve has moved to left. The steam now passes through P_2 to the right of the piston and the " used " steam (to the left of the piston) escapes into X. If, then, the slide-valve moves backwards and forwards at the right times, the steam passes to each side of the piston as required. The rod R is joined to a kind of crank (not shown in Fig. 42) on the main axle. The piston turns the axle, as we have already described and the axle and second crank move the slide-valve. The engine therefore moves its own slide-valve at the proper speed.

The " used " steam which passes out through X may escape into the air, as in a railway engine, or into special



(*By courtesy of the North Eastern Marine Engineering Co.* (1938) *Ltd.*)

A three-cylinder marine (ship) engine. The cylinders (at the top) are upright and are supported at the front by three steel pillars. The piston rods (almost as thick as the pillars) and the cranks can be seen.

"condensers." Steam-engines used for driving ships always have condensers. On a ship there is only a limited supply of fresh water. The water from the steam which condenses can be used again in the boiler.

Let us now think over the whole working of a steam-engine. The engine does useful work for us. From where, exactly, has the power come? We start with cold water in the boiler. We heat it and turn it into steam. The hot steam pushes the piston, and, in doing so, does some work. When the steam escapes it is cooler. At last it turns back into water, either in the air or in the condensers. We have not used up any water but *we have used up some heat*. The engine has changed some of the heat which was supplied to the boiler into useful work; the water and steam merely helped to bring about this change. Does a steam-engine make good use of the heat which is supplied to it? Not all the heat from the fire goes into the water, the steam loses some heat on its way to the cylinder, the steam which comes out of the cylinder is still hot and therefore carries some heat away with it. There are many awkward moving parts, such as the piston and the crank, and some of the power of the engine is used in overcoming friction. Much of the heat which is supplied is wasted and only a part of the heat is changed into useful work. An ordinary steam-engine changes only about $\frac{1}{10}$ of the heat into useful work. This, you may think, is very poor. It *is* poor but scientists have not yet found ways of making much improvement.

Towards the end of the last century another kind of steam-engine was invented. As it gives a round-and-round movement immediately, there is no need for an awkward piston and crank, and, as we might expect, it therefore makes better use of the heat which is supplied to it. This newer kind of engine is called a steam-turbine. Just as James Watt showed how to make a good steam-engine, so Charles Parsons showed (in 1884) how to make a good steam-turbine.

Fig. 44 is a simple drawing of a steam-turbine. The turning-part, called the "rotor," is like a very thick axle. Sticking out all round it there are rings of blades. The picture on p. 133 shows some of these rings of blades;

notice particularly how the blades are curved. The rotor turns inside a big metal case. There are rings of blades sticking out from the inside surface of the case. These rings fit between the rings on the rotor. The steam goes

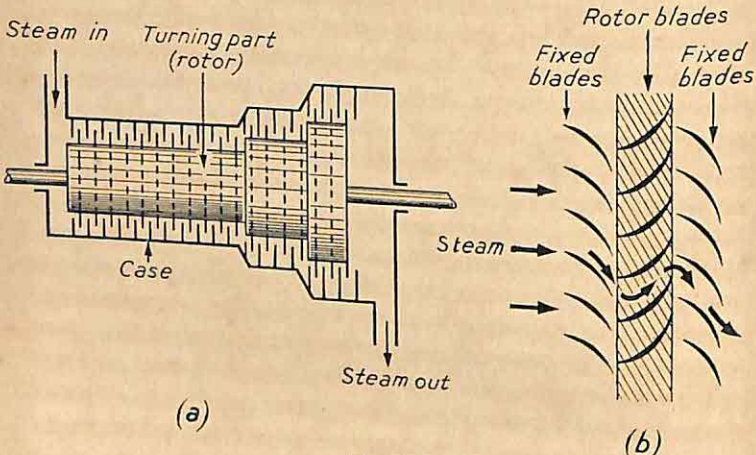
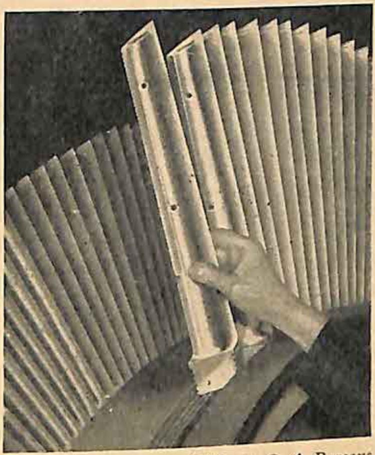


FIG. 44.

in at one end of the case (the narrower end), passes *between* the blades (both those of the rotor and those of the case), and comes out at the other end. Now look at Fig. 44 b. It shows part of one ring of blades of the rotor between parts of two rings of the case, as if you were looking at the ends of the blades. Notice that the blades on the rotor and the blades in the case are curved in opposite directions. The steam keeps changing its direction as it rushes between the blades. It rushes out from between the rotor blades at an angle. If you jump forwards off a log which is floating in a lake, the log is pushed backwards. You move one way; the log is pushed the other way. In a similar way, the steam rushes out from between the rotor blades in one direction and so pushes the blades backwards in the other direction. This backward push on all the rotor blades makes the rotor turn with great power.



(By courtesy of Messrs. C. A. Parsons & Co. Ltd.)

Turbine blades. (These long blades are at the "low pressure" end of the turbine.)

A good steam-turbine changes about $\frac{3}{10}$ of the heat supplied to it into useful work. It is therefore better than a steam-engine. But it is a very big, heavy engine. It would not be suitable for driving small machines in a factory or even for pulling trains. It is used chiefly for driving big steamships and electric generators in "power stations."

We now pass to a completely different kind of heat-engine. In this kind the fire is put inside the cylinder! We could not conveniently burn a solid fuel like coal inside a cylinder, but it would not be so difficult if we used a liquid fuel (such as oil) or an inflammable gas. Further, we should not then need steam; the hot gases from the burning fuel could be used instead. Motor-car engines and aeroplane engines depend upon this idea. We call such engines "internal combustion engines" which means, of course, "inside-burning engines."

The best-known internal combustion engine is that in a motor-car. The fuel is petrol. A mixture of petrol and air is passed into the cylinder. (The petrol is sent in as a kind of mist so that it quickly turns into a vapour.) A little electric spark, made by means of a "sparking plug," sets light to the petrol. The burning is so fast that we sometimes call it an explosion. Great amounts of very hot gases are made. These gases, being in a small space, press very strongly. They push on the piston. After they have moved the piston they escape from the cylinder and come out of a pipe at the back of the car.

Fig. 45 helps you to understand the details of the working of the engine. In each drawing you can see the piston in the cylinder, the piston rod, and the crank. The sparking plug S fits in a hole at the top of the cylinder. The mixture of petrol and air enters the cylinder through the pipe P_1 and the "used" gases come out through the pipe P_2. Each pipe is guarded by a valve. The valves are like doors. They open and close the pipes. (The drawing does not show how the valves are worked.) In drawing 1, for example, the left-hand valve is open so that petrol and air can enter. In drawings 2 and 3 both valves are shut. In drawing 4 the right-hand valve is open so that the "used" gases can escape.

There are four steps in the working of the engine. These are shown in the four drawings of Fig. 45. In step 1 the piston is moving downwards and the left-hand valve is open. The mixture of petrol and air enters the cylinder.

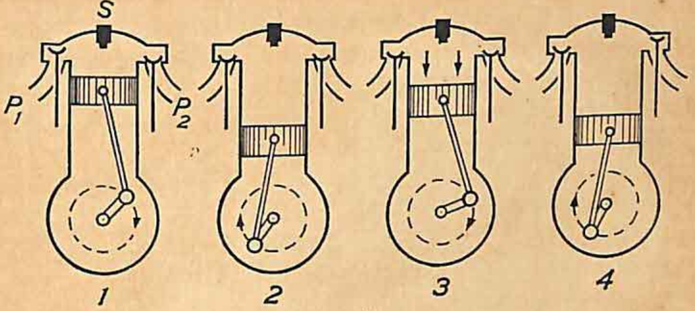
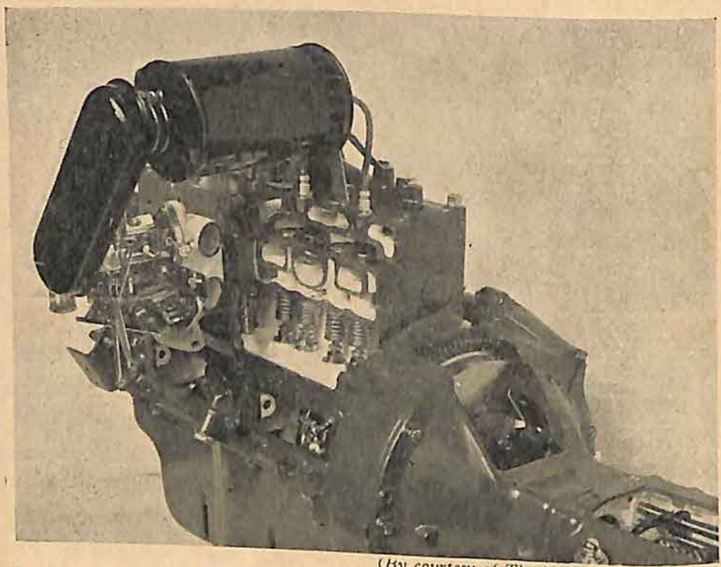


FIG. 45.

In step 2 the piston is moving upwards and both valves are shut. The piston is pressing the mixture into a smaller space. At the end of this step the electric spark is made. The petrol burns very quickly. The hot gases push the piston down (step 3). In step 4 the piston is moving upwards again and the right-hand valve is open. The " used " gases are pushed out. These four steps take place over and over again.

We notice that, unlike the steam-engine, the hot gases push only on one side of the piston, and, further, they push only in one step (the 3rd) of the four. Even with a fly-wheel (p. 128) on the axle, the turning would be far from steady. In a motor-car engine there are four (or more) cylinders. The four pistons all turn the same axle. The pistons are arranged so that, at any moment, each is making a different step. One, therefore, is always making step 3 and the axle is turned steadily.

The engine obtains its power from the burning of petrol; it changes heat into work. It is not easy to picture the many little " fires " which take place at great speed when the engine is working. When a six-cylinder car runs at moderate speed there are about $\frac{1}{4}$ million separate little fires in an hour ! A petrol engine changes about $\frac{1}{4}$ of the



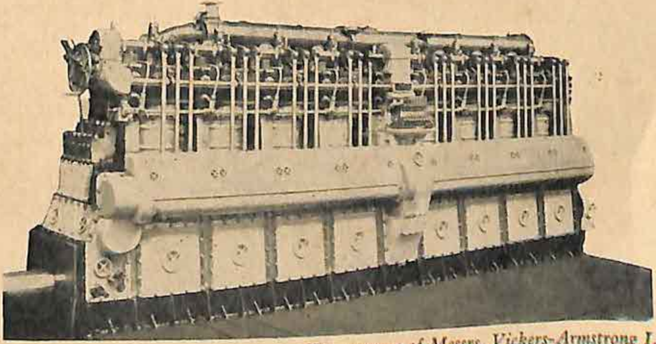
(*By courtesy of The Nuffield Organisation*)

Part of this motor-car engine has been cut away so that you can see inside. How many of the parts can you recognise ?

heat from the petrol into useful work. It is therefore better than a steam-engine but not so good as a turbine. Its chief advantage is that it is small and light in weight. It is very suitable for motor-cars and aeroplanes, in fact, the aeroplane only became possible when this kind of engine had been invented.

In recent years another kind of internal combustion engine has been developed. It is called the Diesel engine. The fuel is heavy oil. The engine works in the same four steps as a petrol engine but there is one important difference. That is the way in which the oil is set alight. In step 1 air, *but no oil*, enters the cylinder. In step 2 the piston presses the air into a very small space, much smaller than in a petrol engine. *This makes the air very hot.* At the end of this step a little oil is pumped into the cylinder. The air is so hot that the oil immediately burns. The hot gases push down the piston (step 3) and, as in a petrol engine, escape in step 4.

The Diesel engine is better than a petrol engine in two ways. It uses heavy oil which is cheaper than petrol and it changes nearly ⅖ of the heat into useful work. This is the best kind of heat-engine which has been invented. But Deisel engines are not as common as petrol engines because the Diesel engine is very heavy. The air is pressed so strongly that the engine must be made of thick, heavy metal. In places where the weight of the engine is not important, the Diesel engine is very useful. It is used for driving some kinds of ships, working heavy pumps, and sometimes for driving machines in factories. It has been used in heavy motor-lorries and railway trains. It is possible that, one day, the Diesel engine will be the most useful way in which Man "makes fire work for him."



(By courtesy of Messrs. Vickers-Armstrong Ltd.)

This large oil engine has eight cylinders and gives 1,200 horse-power when working at 500 turns a minute.